

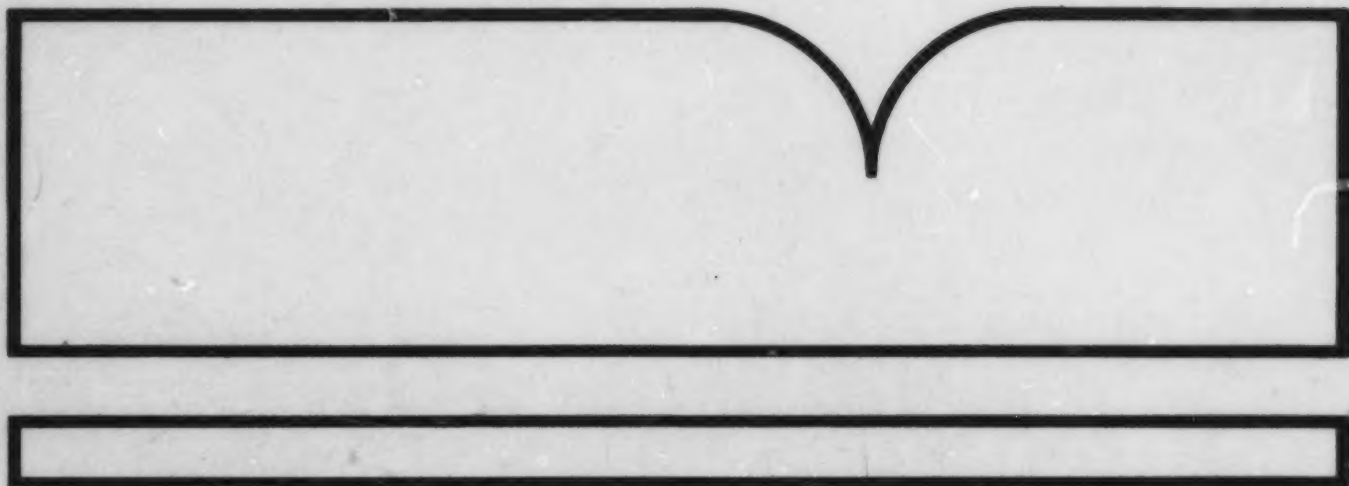
Assessment of Hazard Potential from
Combustion of Wastes in Industrial Boilers

Research Triangle Inst.
Research Triangle Park, NC

Prepared for

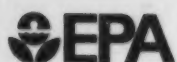
Industrial Environmental Research Lab.
Research Triangle Park, NC

Jul 81



U.S. Department of Commerce
National Technical Information Service

NTIS



United States
Environmental Protection
Agency

EPA-600/7-81-108

July 1981

P881-221889

Research and Development

ASSESSMENT OF HAZARD
POTENTIAL FROM COMBUSTION OF
WASTES IN INDUSTRIAL BOILERS

Prepared for

Office of Air Quality Planning and Standards

Prepared by

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

cover 1

NOTICE

THIS DOCUMENT HAS BEEN REPRODUCED FROM THE BEST COPY FURNISHED US BY THE SPONSORING AGENCY. ALTHOUGH IT IS RECOGNIZED THAT CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED IN THE INTEREST OF MAKING AVAILABLE AS MUCH INFORMATION AS POSSIBLE.

TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)		
1. REPORT NO. EPA-600/7-81-108	2.	3. RECIPIENT'S ACCESSION NO. PBM 22188 9
4. TITLE AND SUBTITLE Assessment of Hazard Potential from Combustion of Wastes in Industrial Boilers		5. REPORT DATE July 1981
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) J. W. Harrison, J. B. White, and W. J. King		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Research Triangle Institute P. O. Box 12194 Research Triangle Park, North Carolina 27709		10. PROGRAM ELEMENT NO. 1NE827
		11. CONTRACT/GRANT NO. 68-02-3170, Task 21
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Task Final; 6/80 - 4/81
		14. SPONSORING AGENCY CODE EPA/600/13
15. SUPPLEMENTARY NOTES IERL-RTP project officer is Wade H. Ponder, Mail Drop 2818, 919/541-2818.		
16. ABSTRACT The report gives results of a study to determine the extent of the present onsite use of waste fuel in industrial boilers and related process equipment, the nature and quantities of the materials so disposed of, and current regulations concerning such use. The study responds to a request for comment and advice on recently promulgated hazardous waste regulations that allow the onsite use of wastes as fuels with few restrictions. Based on contacts with federal, state, and local environmental protection officials, industry personnel, and the open literature, the study concludes that: a wide variety of materials have been burned as fuel in standard or appropriately modified combustion equipment; the practice can be expected to expand due to the economic pressures of hazardous waste disposal and rising fossil fuel costs; virtually no emission data on waste fuel combustion (except through incineration) is available; under conditions of inefficient combustion, significant particulate matter and high molecular weight (including polycyclic organic compounds) emission rates can be expected; and, within the scope of this study, no current regulations were found to be directed specifically at waste combustion. The study recommends increased industry contacts, representative site selection, and a field program in conjunction with a coordinated regulatory program.		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B 06T
Wastes	Stationary Sources	14G
Hazardous Materials	Hazardous Wastes	11G
Combustion	Waste Fuels	21B
Boilers	Industrial Boilers	13A 07C
Assessments	Environmental Assessment	14B
18. DISTRIBUTION STATEMENT Release to Public		19. SECURITY CLASS (This Report) Unclassified
		20. SECURITY CLASS (This page) Unclassified
		21. NO. OF PAGES 122
		22. PRICE

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

EPA REVIEW NOTICE

This report has been reviewed by the participating Federal Agencies, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

i.a

Cover 2

EPA-600/7-81-108

July 1981

**ASSESSMENT OF HAZARD POTENTIAL FROM COMBUSTION
OF WASTES IN INDUSTRIAL BOILERS**

by
James W. Harrison
James B. White
William J. King
Research Triangle Institute
Research Triangle Park, North Carolina 27709

EPA Contract No. 68-02-3170
Work Assignment 21
Program Element No. 1NE827

Project Officer
Wade H. Ponder
Chemical Processes Branch
Industrial Environmental Research Laboratory
Research Triangle Park, North Carolina 27711

Prepared for:
U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20460

Abstract

The Resources Conservation and Recovery Act of 1976 encourages the conservation of valuable resources, including energy, consonant with the protection of environmental quality. Recently promulgated hazardous waste regulations allow the onsite use of wastes as fuels with few restrictions, although EPA's Office of Solid Waste has asked for comment and advice on this matter. In response, the present study was undertaken to determine the extent of the present onsite use of waste fuel in industrial boilers and related process equipment, the nature and quantities of the materials so disposed, and the current regulations concerning such use.

Based upon contacts with Federal, State, and local environmental protection officials as well as industry personnel and the open literature, this study concludes that: a wide variety of materials have been burned as fuel in standard or appropriately modified combustion equipment; the practice can be expected to expand due to the economic pressures of hazardous waste disposal and rising fossil fuel costs; virtually no emission data on waste fuel combustion (except through incineration) is available; under conditions of inefficient combustion, significant particulate matter and high molecular weight (including polycyclic organic compounds) emission rates can be expected; and, finally, within the scope of this study, no current regulations were found to be directed specifically at waste combustion.

Recommendations for increased industry contacts, representative site selection, and a field program in conjunction with a coordinated regulatory program to assure the environmentally safe use of wastes as fuel are made.

This work, under Contract 68-02-3170, Work Assignment 21, was carried out between June 5, 1980, and September 30, 1980.

TABLE OF CONTENTS

	<u>Page</u>
Abstract	ii
List of Tables	v
List of Figures	vii
1. INTRODUCTION	1
2. CONCLUSIONS AND RECOMMENDATIONS	5
2.1 Conclusions	5
2.2 Recommendations	7
3.0 MATERIALS	13
3.1 Requirements for Energy Recovery	13
3.2 Candidate Species	16
3.3 Thermal Destruction Considerations	25
3.4 Industrial Use Patterns	32
4.0 INVENTORIES	38
4.1 Data From Federal Studies	38
4.2 Data From State Studies	40
5.0 COMBUSTION TECHNOLOGY	47
5.1 Industrial Boiler Population	47
5.2 Typical Combustion Conditions	51
5.3 Burner Design and Operation in Cofiring	51
6.0 CURRENT DISPOSAL PRACTICE	57
6.1 Federal Sources	57
6.2 State Sources	58
6.3 Nongovernmental Sources	66
6.4 Trends in Industrial Waste Combustion	71
7.0 EMISSION DATA AND SOURCE TESTING	70
7.1 Data on Hand	70
7.2 Data Needed	77
7.3 Site Selection	78
7.4 Source Testing Overview	81
8.0 CONTROL TECHNOLOGY	84
8.1 Combustion Conditions	84
8.2 Solid Wastes	86
8.3 Air Emission Controls	87

TABLE OF CONTENTS (Continued)

	<u>Page</u>
9.0 CURRENT REGULATORY APPROACHES	91
9.1 Regulation by the Office of Solid Waste	91
9.2 Regulation by the Office of Air Quality Planning and Standards	92
9.3 Regulation by the States	97
9.4 Assessment of Regulatory Status	100
REFERENCES	103

LIST OF TABLES

<u>Table</u>	<u>Page</u>
2.1 PROPOSED AGENDA FOR JOINT INDUSTRY-EPA WORKSHOP ON THE ENVIRONMENTALLY SAFE USE OF WASTE MATERIALS AS FUEL	9
3.1 BASIC CONSIDERATIONS IN WASTE FUEL SELECTION	14
3.2 WASTE GASES FIRED IN INDUSTRIAL BOILERS	16
3.3 LIQUIDS USED IN INDUSTRIAL BOILERS	17
3.4 TYPICAL AQUEOUS WASTE FIRED FOR HEAT RECOVERY	18
3.5 CRANK CASE OIL CONTAMINANTS, ST. LOUIS AREA, 1970	19
3.6 REPRESENTATIVE SOLVENTS USED IN THE PHARMACEUTICAL INDUSTRY	21
3.7 SOLID WASTES PRESENTLY BURNED IN INDUSTRIAL APPLICATIONS	22
3.8 SOLID WASTE FROM THE CHEMICAL INDUSTRY	23
3.9 SOLVENT RECLAMATION RESIDUE	24
3.10 ANALYSIS OF SLUDGE FROM SOLVENT RECLAMATION	24
3.11 HEAT VALUE OF PLASTIC WASTE	25
3.12 CALCULATED DESTRUCTION TEMPERATURE FOR SELECTED COMPOUNDS	31
3.13 SOURCES OF SOLVENTS EMISSIONS	32
3.14 WASTE OIL INVENTORY	33
3.15 END USE OF SOLVENT WASTE GENERATED BY DEGREASING OPERATIONS	34
3.16 PROXIMATE ANALYSIS OF WASTE TIRES VS. COAL	37
4.1 QUANTITIES OF WASTE FROM VARIOUS INDUSTRIES ESTIMATED FOR ENERGY RECOVERY	39
4.2 CLASSIFICATION OF SOLVENT END USES INTO INDUSTRIAL AND CONSUMER/COMMERCIAL USAGE SECTORS	41
4.3 VOLUMES OF WASTES GENERATED IN THE STATE OF OREGON, 1972-1973	42
4.4 VOLUMES OF WASTE GENERATED IN THE STATE OF MASSACHUSETTS IN 1976	42
4.5 MAJOR VOLUMES OF HAZARDOUS WASTES BY TYPE IN NEW YORK STATE	44
4.6 LISTING OF TYPES AND QUANTITIES OF HAZARDOUS WASTES GENERATED BY THE TEXTILE INDUSTRY (SIC-22) IN NORTH CAROLINA	45
4.7 DISPOSAL LOCATIONS FOR PROJECTED WASTES FROM ILLINOIS INDUSTRY	46
5.1 DISTRIBUTION OF COMMERCIAL/INDUSTRIAL BOILERS BY SIZE	48
5.2 BOILER POPULATION DISTRIBUTED BY HEAT TRANSFER CONFIGURATION	50
5.3 DISTRIBUTION OF NONUTILITY BOILERS BY SECTORS	50
5.4 SUMMARY OF THE TOTAL BOILER POPULATION BY FUEL USED	50
5.5 RANGE OF LIQUID WASTE PROPERTIES	53
6.1 SUMMARY OF ONSITE TREATMENT METHODS OF HAZARDOUS WASTES IN NEW YORK STATE	59
6.2 WASTES RECLAIMED FOR FUEL OR MATERIALS IN NEW YORK STATE	60
6.3 TYPES OF WASTE AND QUANTITIES (ANNUAL) BURNED ONSITE AS FUEL BY ILLINOIS INDUSTRIES	62
6.4 LIQUID WASTES BURNED FOR ENERGY RECOVERY IN CONVENTIONAL HEATING EQUIPMENT	68
6.5 IN-PLANT SOLID WASTE FUELS	70

LIST OF TABLES (Continued)

<u>Table</u>	<u>Page</u>
7.1 ANALYSIS FOR NO.2 DISTILLATE FUEL AND WASTE OIL BURNED IN ABERDEEN PROVING GROUND TESTS	73
7.2 COMBUSTION-EMISSION RESULTS FROM TESTS AT ABERDEEN PROVING GROUND .	73
7.3 SUMMARY OF DATA ON QUANTITIES OF LEAD EMITTED WITH FLUE GAS AS A PERCENTAGE OF LEAD ENTERING WITH WASTE OIL FUEL	74
7.4 TYPICAL PARTICLE SIZE DISTRIBUTION OF ASH GENERATED IN HEARTH-BURNING OF PLASTIC	76
7.5 SAMPLES FOR LEVEL 1 SOURCE SCREENING FOR WASTE COMBUSTION	83
8.1 GROUND LEVEL CONCENTRATION OF LEAD IN AMBIENT AIR FOR WORST CASE METEOROLOGICAL CONDITIONS AT VARIOUS DOWNWIND DISTANCES, x	89
8.2 GROUND LEVEL CONCENTRATION OF LEAD IN AMBIENT AIR FOR MODERATE CASE METEOROLOGICAL CONDITIONS AT VARIOUS DOWNWIND DISTANCES, x	90
8.3 GROUND LEVEL CONCENTRATION OF LEAD IN AMBIENT AIR FOR BEST CASE METEOROLOGICAL CONDITIONS AT VARIOUS DOWNWIND DISTANCES, x	90
9.1 SOLVENTS LISTED AS OF MAY 19, 1980, AS HAZARDOUS WASTE	93
9.2 PRINCIPAL AIR POLLUTION REGULATORY OPTIONS	95
9.3 NATIONAL AMBIENT AIR QUALITY STANDARDS	96
9.4 NATIONAL EMISSION STANDARDS FOR HAZARDOUS AIR POLLUTANTS	97

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1.1 Definition of solid waste	2
2.1 Comparative schedule for recommended program elements	11
3.1 Comparison of thermal destruction of three pesticides	27
3.2 Thermal destruction profiles	28
3.3 Thermal destruction profiles for individual compounds in the combined samples	29
3.4 Effect of residence time at 704°C	30
3.5 Typical disposal and reuse pattern for industrial used oil	35
5.1 Possible combinations of characteristics associated with U.S. industrial/commercial boilers	49
6.1 Projected industrial waste disposal in Illinois statewide	63
7.1 Qualitative comparison of organic wastes state and combustor type in achieving high combustion efficiency	80
7.2 Sample points for generalized source screening tests	82
9.1 Preferred standards path analysis flow chart for air quality programs	94

1.0 INTRODUCTION

The Resource Conservation and Recovery Act of 1976 (RCRA) [1] has among its objectives "to promote the protection of health and the environment and to conserve valuable material and energy resources by ... (4) regulating the treatment, storage, transportation, and disposal of hazardous wastes which have adverse effects on health and the environment; ...(7) promoting the demonstration, construction, and application of solid waste management, resource recovery, and resource conservation systems which preserve and enhance the quality of air, water, and land resources;"

In formulating and promulgating the regulations for classifying and dealing with hazardous wastes [2], the Office of Solid Waste has deemed the recovery of energy from waste combustion to be consonant with congressional intent as expressed in objective (7) of the RCRA, cited above.

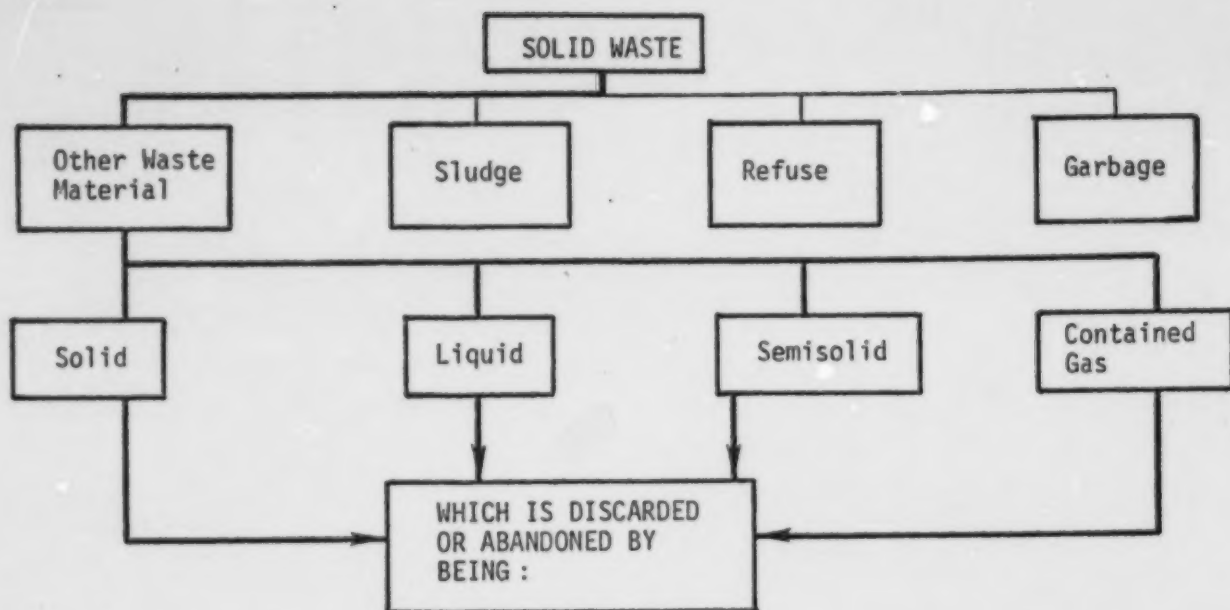
Specifically, Part 261 of Title 40 of the Code of Federal Regulations (CFR) [3] defines solid waste as shown in Figure 1. The regulation also includes criteria for determining whether or not solid wastes are hazardous. The effect of the exclusionary definition in Figure 1 is to allow ignitable materials which would otherwise be classified as hazardous to be regarded as nonhazardous if they are burned onsite as fuel for energy recovery.

In Subpart C, Characteristics of Hazardous Waste [4], criteria and tests for ignitability classification of liquids, solids, and compressed gases are discussed. No criteria are stated for the classification of a gas or vapor as a hazardous waste.

These definitions indicate the following:

1. There is no regulation of the onsite burning of gases or vapors to recover energy. Thus CO generated in catalytic crackers and VOCs resulting from processes or solvent use could be burned to recover energy without the imposition of regulations.

2. There is no regulation of the burning of liquids, semisolids or solids, or any contained gases to recover energy. One point that is not clear at present is when and where the burning to recover energy must take place. In fact, as presently written, it appears that any material (with the exception of several solvents specifically listed as hazardous) which is intended



1. DISPOSED OF

2. BURNED OR INCINERATED, EXCEPT WHERE THE MATERIAL IS BEING BURNED AS A FUEL FOR THE PURPOSE OF RECOVERING USABLE ENERGY

3. PHYSICALLY, CHEMICALLY, OR BIOLOGICALLY TREATED IN LIEU OF, OR PRIOR TO, BEING DISPOSED OF

THIS EXCEPTION INDICATES THAT WASTE MATERIALS WHICH ARE BURNED ONSITE AS FUEL FOR THE PURPOSE OF RECOVERING USABLE ENERGY ARE NOT "SOLID WASTE" WHICH IS "DISCARDED" AND ARE, THEREFORE, NOT SUBJECT TO CONTROL OR REGULATION BY RCRA.

Source: Federal Register, Vol. 45, No. 98, Monday, May 19, 1980, EPA-Hazardous Waste and Consolidated Permit Regulations, 33119 Article 261.2.

Figure 1.1 Definition of solid waste

for use as a fuel (or fuel supplement) can be considered to be excluded from the rules of Parts 262 through 265 because:

- a. These CFR Parts apply to hazardous wastes;
- b. A hazardous waste, according to the criteria of Part 261, must be, by definition of paragraph 261.3 [5], a solid waste; and
- c. The definition of a solid waste, according to paragraph 261.2 [6], has the exclusion of materials burned as fuels to recover energy, as shown in Figure 1.

These observations indicate that a significant change in disposal practice may be expected to occur. In addition, the RCRA-based testing, classifying, handling, transporting, and disposing of hazardous waste [2] will be complex, troublesome, and expensive for every generator of such wastes in the nation. Many wastes which were previously discarded may now be burned in an attempt to qualify under the exclusionary definition. These wastes could include synthesis process wastes, solvents, and lubricants, among other organics. A further stimulus to such use is the escalating prices of the conventional fossil fuels that have heretofore been used almost exclusively for energy production. Any materials which can supplement fossil fuels, at lower costs per Btu, will be seriously considered for use.

The Office of Solid Wastes is aware of the many possible consequences of the combustion allowed under the present exclusion, and it plans to begin consideration of the problems of spent solvents and waste oil in the fall of 1980 and of organic chemical process residues in the fall of 1981 [7]. It has invited comments on such further regulations and specifically solicits information dealing with their use in industrial boilers [8], viz:

"For example, where wastes might be burned as a supplemental fuel in industrial boilers, proposals on fuel ratios, burning temperatures, emission control requirements, and residue disposal requirements would be useful. Obviously, the more specific and constructive the suggestions, the more helpful they will be in our rulemaking."

In response, the work reported here was undertaken to determine if such onsite burning could present an air quality problem.

The Office of Air Quality Planning and Standards (OAQPS), in conjunction with the IERL-RTP and IERL-Cinn, has started a program to collect information on the current practice of waste-burning in industrial boilers and other

process heating equipment the types and quantities of materials burned, the state-of-the-art of technology for waste combustion and waste/fossil fuel co-firing, and the current environmental regulations and policies of State and Federal environmental protection organizations. In addition to the assessment of current waste combustion practices, OAQPS is also planning to assess how the practice of waste combustion in industrial heating equipment might be carried out in the future under various regulatory scenarios that will encourage the complete use of suitable materials for energy recovery commensurate with adequate safeguards for human health and environmental quality.

The purpose of this initial work in the OAQPS/ORD program is to scope the problem and make recommendations about what should be done by EPA to meet its responsibilities with regard to the intent of Congress as expressed in the objectives of the RCRA. The conclusions reached on the basis of this initial study and recommendations for future work are given in Section 2.

It must be emphasized that the information reported here in no way represents an exhaustive survey. The intent was to collect enough data from several Federal and State sources as well as from prior reports and the open literature in order to obtain an idea of what kinds of materials might be used for fuel, an order of magnitude estimate of the quantities of these materials used in industry, some indication of how these materials are, or might be, burned as a fuel in standard industrial combustion equipment, and what air quality impacts might be expected.

Another purpose was to find out, on the basis of a limited survey, how current environmental regulations are being interpreted by Federal and State enforcement officials with regard to such waste-burning and how those officials felt that they might be, or should be, regulated in the future.

With this caveat on the limitations of the study stated, the reader is now invited to critically consider the conclusions and recommendations of the next section on the basis of the information presented in the rest of the report.

2.0 CONCLUSIONS

Based on the information presented in subsequent sections of this report, conclusions are presented concerning the nature and extent of industrial waste-burning, possible environmental consequences, and the present regulatory posture with respect to this practice. Following this, a series of recommendations are made concerning research that should be performed to identify and quantify anticipated pollutant emission rates and to develop the necessary data base to support standards development, if needed.

2.1 Conclusions

The brief survey performed of existing data and current industrial waste combustion practice supports the following conclusions.

1. Waste Inventory Data. Federal surveys have, of necessity, been relatively aggregated to provide overall estimates of wastes generated by SIC industrial categories. Many States have conducted hazardous waste surveys that provide more definition of waste types and quantities that give a better understanding of the diversity of materials that can be burned for energy recovery. Notable in the survey reported here are the data available from the States of: Illinois, Massachusetts, New York, and North Carolina.

In particular, the inventory data of New York and of Illinois offer the best bases for a more in-depth study of current disposal practice and a projection of future trends. Both States are heavily and diversely industrialized, thus providing a convenient cross section to include many of the waste materials and combustion equipments that are used.

Using these two States as examples, the present extent of waste combustion and a future projection can be compared. In New York, as much as 90,000-100,000 m³ of wastes with an energy content of 28,000 MJ/m³ may be annually burned onsite as fuel. The rate of organic waste generation is such that this figure could double. Based on an industry survey in Illinois, only 20 percent, or 8,100 m³ out of 40,500 m³, of waste oil annually is acknowledged to be burned onsite as fuel, as is only 9.7 percent, or 2,605 m³ out of 26,900 m³, of solvents. The other alternative for disposal is listed as "recycle/reclaim." As the price of fossil fuel increases, these percentages will probably escalate.

2. Combustion Technology & Practice. A wide variety of waste materials has been burned in standard combustion equipment or equipment modified to accept wastes with or without fossil fuel. The combustion technology base for increased utilization is available. Cost of the RCRA manifest system for tracking hazardous wastes and the increasing price of fossil fuel can be expected to push the technology and practice to make waste use as a fuel an accepted feature of industrial energy supply.

3. Emission Data. Virtually no emission data on waste combustion in industrial combustion equipment (excepting incinerators) are available. Field tests are needed to fully characterize sources burning wastes and provide the basis for formulating and implementing air quality controls, if needed.

4. Potential Air Quality Problems. Some organic wastes contain relatively large amounts of metals or metal-containing compounds that can volatilize as metal vapor or oxides, or can produce fly ash in much larger amounts than usual with fossil fuels. This is supported by existing emissions data, although limited. In addition, many wastes differ appreciably from fossil fuels in their physical properties. This can lead to inefficient combustion with the production of carbonaceous particles and polycyclic organic compounds. The latter has not yet been verified by emissions measurements--as far as could be determined in the present study--but can be inferred from the behavior observed when firing fossil fuels inefficiently in conventional combustion equipment.

An example of one problem that can occur, the use of waste, lead-bearing, crankcase oil can cause emissions of lead into ambient air in quantities that greatly exceed NAAQS values. Feedstock lead content limitations and/or particle control techniques should be considered to prevent the degradation of air quality.

5. Current Regulations. The current regulatory status concerning waste combustion in boilers can be fairly summarized as a state of limbo. Heretofore, the combustion of waste materials as fuel represented only a very small fraction of the total material burned. As such, the problem was minute. Now that there is a strong trend toward much more such combustion, there is a question as to whether current regulations are sufficient to provide adequate control to assure air quality.

This question cannot be answered until much more is known (i.e., quantitative data are obtained) about the waste fuel composition, the conditions of combustion, the species emitted, and their dependence on feed and firing conditions. In addition, there is much to be learned about the operating practices and maintenance required to assure essentially complete combustion is guidelines are to be prepared.

Many States now have regulations that require a fuel analysis and notification of the State agency before a permit holder is allowed to burn a significantly different fuel. There is evidence that this requirement is not, and perhaps cannot, be enforced.

In cases where notification and a fuel analysis are provided, the States have generally done some dispersion modeling by looking at SO_2 and perhaps lead. PCB-contaminated oil is a special case. There has been sufficient publicity, public arousal, and EPA and State guidelines for compliance to be effected.

It is incumbent upon EPA to assure that field measurement methods that develop representative data are available. The presence of pollutant species must be proved and concentrations quantified; then health risk assessments must be made in order to provide the basis for regulation.

In the interim, it appears that enforcement of existing particulate emission and opacity regulations is the first line of air quality defense. Collection of particles, especially at low enough temperatures to effect adsorption of higher molecular weight organics, can serve to greatly reduce the emission of metals and polycyclic organic compounds. Whether or not this is adequate must be decided on the basis of field measurements.

The regulatory problem is to balance air, water, and land environmental quality with resource recovery.

2.2 Recommendations

Under the RCRA mandate, EPA has the responsibility to promote resource recovery commensurate with the protection of environmental quality. In order to carry out this responsibility with regard to the use of waste as fuel, EPA must provide guidelines to industry to promote environmentally sound usage and must formulate regulations, if needed, to insure environmental protection. Fundamental to the preparation of guidelines and regulations is an under-

standing of the technology and practice, both current and anticipated, of waste/fossil fuel cofiring, the pollutant emissions resulting from this practice, and effective methods of control.

1. Workshop. To promote communication between industry and EPA, a workshop on the environmentally safe use of waste materials as fuel should be held as soon as practicable. A proposed agenda for such a workshop is shown in Table 2.1. This event should be well publicized through industry association organizations, professional groups such as NSPE, ASME, and the AIChE, and to State environmental protection officials. It should be repeated periodically, perhaps in a symposium format.

2. Disposal Practice Survey. A detailed study should be carried out with the cooperation of State environmental protection officials using air emissions permit information and hazardous waste inventory information to develop a list of specific sources, burning known waste materials that are representative of those SIC classes which can reasonably be expected to burn significant (with respect to air quality) amounts of waste. This study should be confined to two or three States (e.g., New York, Illinois, and Massachusetts). The objective would be to develop a list of potential test sites to which selection criteria could be applied to choose sites for field measurements that would provide the basis for identifying those waste materials, combustion conditions, pollutants, and emission rates that would cause air quality problems unless adequately controlled.

3. Site Selection. Criteria for selection of field test sites should be formulated and applied to the candidate source list.

4. Site Test Plan. Test plans specific to each of the selected sources should be developed. These should include screening-type measurements (Level 1) plus any additional sampling and analysis required to characterize the source by relating waste-feed composition, combustion conditions, and emissions. In those cases where the source is known to be representative of a large group of similar sources, it may be desirable to combine the screening measurements with standard reference method measurements, backed by suitable quality assurance audits, to expedite regulations development.

5. Field Measurements. Actual measurements should be performed according to the test plans at the selected sites.

TABLE 2.1. PROPOSED AGENDA FOR JOINT INDUSTRY-EPA WORKSHOP ON THE ENVIRONMENTALLY SAFE USE OF WASTE MATERIALS AS FUEL

First Day

(All Plenary Sessions)

Introduction and Welcome (Invited)
Waste Materials as Fuel (Invited)
Combustion Equipment Design and Operation for Cofiring (Invited)
Emissions Measurement (Invited)
Environmental Controls (Invited)
Environmental Regulatory Concerns (Invited)

Second Day

Charge to Panels - Plenary Session

Parallel Sessions of Panels on:

1. Combustion Equipment Design and Operation
2. Emissions Measurements
3. Environmental Controls

Morning Session: Statement of Issues

Afternoon Session: Recommendations on Resolution of Issues

Third Day

Panel Reports - Plenary Session

Discussion of Reports

Recommendations to EPA

6. Environmental Analysis. Measurement data from the field program should be used to estimate the potential health and environmental impacts due to the aggregate emissions from sources using wastes as fuel. This aggregate emission data should be obtained by extending the in-depth waste inventory and combustion practice survey to all States in which waste combustion as a fuel can degrade air quality measurably. Control technology to reduce emissions to acceptable levels should be identified. If the necessary control technology is not available, the needs should be specified to facilitate necessary R & D.

7. Combustion Technology Research. In parallel with the field program carried out to ascertain the consequences of present practice, a research program should be carried out to elucidate how various equipment design and operation parameters will affect the combustion efficiency of various waste materials used as fuel. This research should take into account recent and planned parallel research efforts by private industry and professional organizations. The objective should be a set of design and operating practice guidelines to promote the efficient combustion of organic waste in industrial boilers and related equipment.

8. Regulatory Analysis. Field data, the results of the environmental analysis, and combustion technology research will provide a series of inputs to EPA's regulatory offices for air, water, and land quality to enable those offices in conjunction to assess the environmental tradeoffs involved in the exercise of regulation through their respective legal mandates. These tradeoffs should be explicitly comparable in terms of quantities of pollutants generated, dispersion mechanisms, and health and environmental risk analyses.

9. Regulation Preparation. Necessary regulation(s) would be prepared on a schedule commensurate with existing program office workloads and priorities. These recommended program elements are shown in a comparative schedule in Figure 2.1.

The rationale for the recommended program is as follows. It is desirable to get industrial input in an advisory rather than an adversary capacity. Establishment and maintenance of a dialog will enhance EPA's understanding of the practice of waste fuel usage as well as promote industrial efforts to do so in an environmentally sound manner. The initial focus on the industrial experience in two States, the early selection of sites, and the acquisition of screening data will provide a better understanding of the pollutants generated

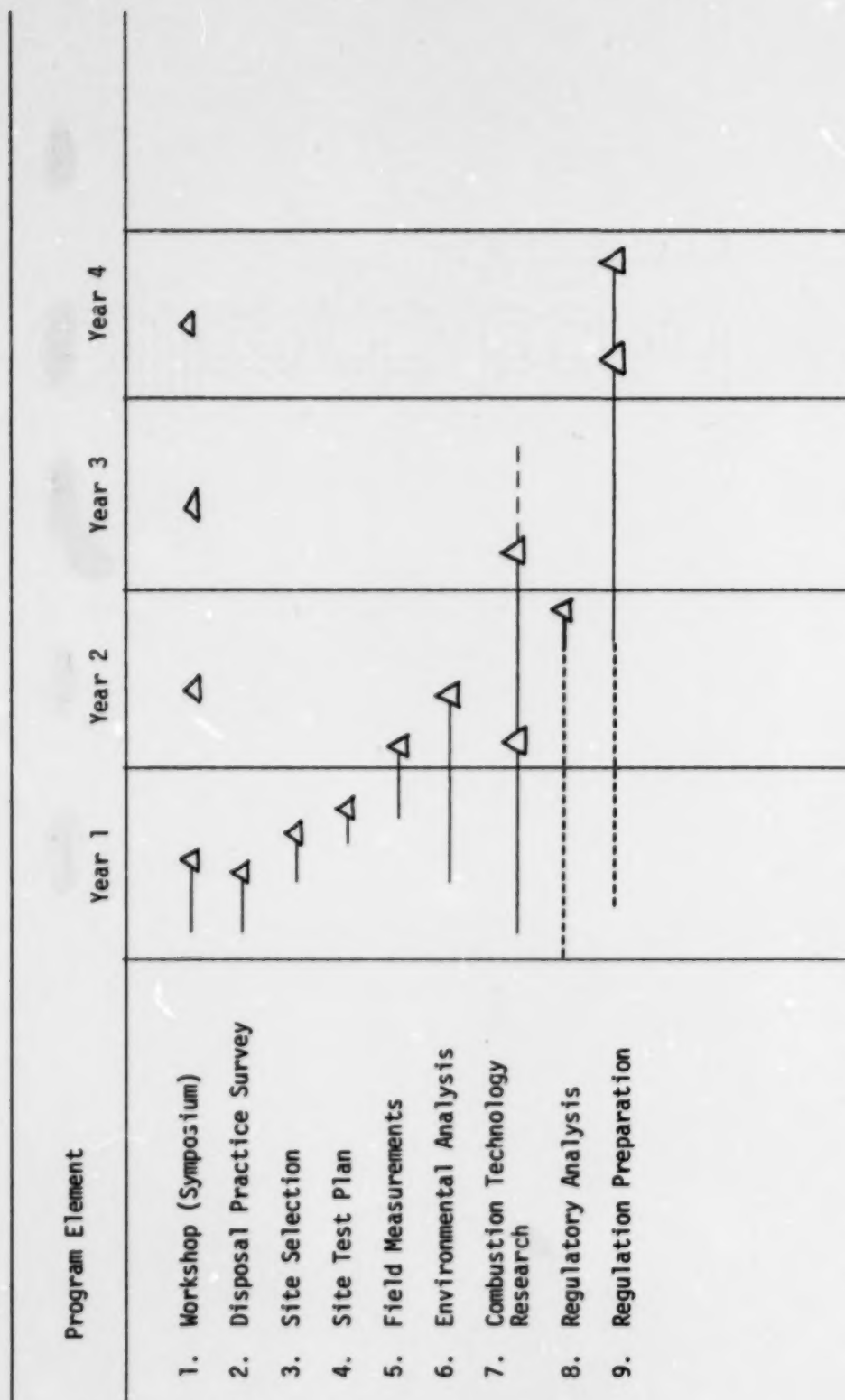


Figure 2.1. Comparative schedule for recommended program elements

and the differences between emissions from wastes and those from fossil fuels. At the same time, if measurements are made by standard methods--with suitable quality control--at some selected site(s), there would be a more defensible set of data should a decision be made early in the program to press for regulations specific to waste-burning.

In parallel with these elements to define current practice and its environmental consequences, a program of waste combustion technology research would provide the basis for specifying recommended designs and operational procedures that would aid industry in using waste fuels. There has already been a great deal of research on refuse-derived fuels (RDF). It should not be repeated. The materials considered should be those liquids, semisolids, and solids that are apt to be generated by and used by industry.

Also, in parallel, the regulatory analysis element of the program considers the environmental consequences of various regulatory approaches. The view taken is that effective regulation will most probably take a coordinated approach between the program offices with mutually supportive policies and, if necessary, regulations. Finally, the regulation preparation portion of the program is taken as possibly starting in mid-1981 if justified by the severity of the perceived environmental problems. If not urgent, the regulation countdown could start late in 1982, allowing the accumulation of sufficient prior R & D outputs and the output of the regulatory analysis phase to set the stage for the actual preparation and promulgation.

3.0 MATERIALS

Although fuels can be defined as any matter which can be used to produce heat by combustion, in practical applications the definition is more restrictive. Special considerations must be given to the physical and chemical properties of a potential fuel source before it can be effectively matched against an existing combustion technology. This section surveys the various waste organics that might be considered for use as fuels, discusses some of their physical and chemical properties, and identifies those industrial classes which are most likely to generate the respective materials and, hence, which might use them for fuel. Also discussed is the information available on the temperature-time relations required for thermal destruction.

3.1 Requirements for Energy Recovery

Problems with waste as fuel derive mainly from the unknown, highly variable nature of waste matter. In order to determine the proper type of combustion system for use with a particular waste, certain basic information about the waste material must be known [9] (see Table 3.1). In an initial screening, the most important of these are physical state, heat content, and fuel-borne contaminants.

Before a waste can be burned as a fuel, its physical state must be suitable for a particular burner type. Physical state is normally classed as gaseous, liquid, or solid. When dealing with waste, however, the difference between solids and liquids is frequently not clear cut. As in the case of still bottoms from solvent reclamation or the chemical industry, physical state is often dependent on the process and how much liquid the industrial processor chooses to leave behind. The distinction between liquids, semi-solids, and solids is therefore made on the basis of viscosity. To be considered as a liquid, a waste must be pumpable at ambient temperature or should be capable of being pumped after being treated to some reasonable temperature (204°-260°C)[9]. This normally restricts the viscosity of the waste to less than 10,000 SSU and solids content to 70 percent by weight [9].

Next, a waste must have a high enough heat content to develop and sustain combustion reactions and maintain required boiler temperatures. The heat

TABLE 3.1 BASIC CONSIDERATIONS IN WASTE FUEL SELECTION [9]

Parameter	Example
Physical state	Gas, liquid, solid, or mixture
Solid	Size, form, quantity
Liquids	Viscosity vs. temperature, sedimentation, volatility, immiscibility, flammability, chemical reactivity, flash point, vapor pressure
Gases	Density, moisture, contaminants including diluents, concentration, volume
Ultimate analysis	Carbon, hydrogen, oxygen, nitrogen, halogens, water, sulfur, heavy metals on "as received" basis
Heating value	Btu/lb or Btu/ft ³ on an "as received" basis
Special characteristics	Toxicity and corrosiveness
Generation rates	Peak, average, minimum (present and future)

content of waste gases can be grouped as High Btu-->5.59 MJ/m³ (>150 Btu/ft³); Medium Btu--3.73-5.59 MJ/m³ (100-150 Btu/ft³); or Low Btu--<3.73 MJ/m³ (<100 Btu/ft³)[10]. The heat content of liquids and solids can be grouped as High Btu-->23.26 MJ/kg (>10,000 Btu/lb); Medium Btu--11.63-23.26 MJ/kg (5,000-10,000 Btu/lb); and Low Btu--<11.63 MJ/kg (<5,000 Btu/lb)[11]. This grouping can only serve as an indicator of a waste's fuel potential. Some liquids with thermal values as great as 23.26-25.59 MJ/kg (10,000-11,000 Btu/lb) are incapable of sustaining combustion, while other wastes with values as low as 10.47 MJ/kg (4,500 Btu/lb) have been burned unassisted [9].

Lastly, a waste must be relatively clean in order to burn properly. After physical state and heat content, fuel-borne contaminants have the greatest effect on the quality and efficiency of combustion. Contaminants in gaseous organic waste include particles, inorganic gases, and water vapor. Particulate matter can foul burner tips and cause erosion of mechanical surfaces, while the presence of other gases can affect the limits of flammability of the waste.

All combustion must take place within the limits of flammability. Any increase in the volume of an air-fuel mixture will affect these boundaries. If the fuel mixture is diluted with additional gases, the rich and lean limits converge forming an envelope. It is impossible to dilute a mixture beyond the point where the convergence occurs and still sustain combustion [12]. In addition, diluent gases, including water vapor and excess air, must be heated to the ignition point of the fuel before combustion can occur. This requires energy that could otherwise be used to sustain the combustion.

Solids, metals, water, and inorganic liquids are the most common contaminants of organic liquid wastes. Not only do water and other liquids require energy to heat and to vaporize, but the relative differences in specific gravities can cause the mixtures to stratify in holding tanks and fuel lines. Chemical reactions cause precipitates to form or can cause polymerization to occur which may affect feed rates. Solids suspended in the liquid waste can also erode or clog burner tips and control devices.

Metals create problems in both solid and liquid waste fuels. If a burner operates at temperatures greater than the fusion point of the metal, slagging and fouling can occur where the metal oxides or carbonates condense. Metals can also form eutectic mixtures on refractory surfaces and result in corrosion

at temperatures much lower than would otherwise be expected. Vanadium is illustrative of the problem that can occur. Its presence in a fuel is characterized by metallurgic attacks, corrosive attacks on the refractories through the formation of eutectic mixtures, and increased conversion of SO_2 to SO_3 via the catalytic action of vanadium oxide [13]. Similar problems have been experienced with Group I metals [13].

3.2 Candidate Species

Waste candidates for fuel can be grouped according to their physical state. Combustible gases involve mixtures of organic vapors entrained in air. In order to be readily useful in conventional combustion equipment, the waste gases must be available at a steady flow rate, in sufficient volume, and with a relatively constant heat content. To sustain combustion under typical boiler operating temperatures of $1,093^\circ\text{--}1,316^\circ\text{C}$, the heat content should be in the Medium- to High-Btu range or to within ± 10 percent of the heat content of natural gas (95 percent methane, $938\text{--}1040 \text{ Btu/ft}^3$) [13]. Waste gases with a heat content of 3.73 MJ/kg (100 Btu/ft^3) have been fired in commercial burners without assistance from any auxiliary fuels. It should be noted that waste gases with thermal values as low as 3.35 MJ/kg (90 Btu/ft^3) have been fired successfully in standard design burner after being preheated to $316^\circ\text{--}371^\circ\text{C}$ [14]. As the heating value of a waste gas declines, however, increasing quantities of an auxiliary fuel are required to sustain combustion. Some waste gases which have been fired in industrial boilers are listed in Table 3.2.

TABLE 3.2 WASTE GASES FIRED IN INDUSTRIAL BOILERS [15]

Waste	MJ/kg (as fired)	Btu/lb (as fired)
Coke oven gas	45.82	19,700
Blast furnace gas*	2.65	1,139
CO gas	1.34	575
Refinery gas	50.71	21,800

* $\text{Btu/ft}^3 = 65\text{--}110 \text{ Btu/ft}^3$

Liquid wastes present fewer problems in combustion than do gaseous wastes. If a waste liquid is primarily organic and relatively clean, it generally can be injected into a burner, mixed with air, ignited, and burned (see Table 3.3). Inorganic wastes, however, have such low-Btu values as to be totally unsuited for further consideration as a potential fuel source.

TABLE 3.3 LIQUIDS USED IN INDUSTRIAL BOILERS [15]

	MJ/kg (as fired)	Btu/lb
Oil wastes (fuel oil residues)	3.72	16,000
Solvents	23.26-37.22	10,000 - 16,000
Spent lubricants	23.26-32.56	10,000 - 14,000
Paints and resins	13.96-23.26	6,000 - 10,000

Organic waste liquids consist of either aqueous solutions of organics miscible with water or nonaqueous mixtures of organics. Aqueous solutions consist of water and organic mixtures in which the water component composes 50-60 percent or more of the total volume of the mixture [16]. Aqueous wastes are highly variable in heat content but can support combustion at lower water concentrations if the heating value is on the order of 11.63 MJ/kg (5,000 Btu/lb) and the theoretical flame temperature is greater than 1,093°C [9].

Since liquids must be converted to gases before combustion can take place, increasing the water concentration of a waste reduces its capacity to burn without specially designed combustors or an auxiliary fuel. Sufficient heat must be available to vaporize both the aqueous and organic components of a waste stream with enough heat remaining to raise the organic component to its autoignition temperature. Water requires 2.33 MJ/kg in order to vaporize and a subsequent 2.09×10^{-3} MJ/kg per °C to raise its temperature from the boiling point of water to the autoignition temperature of the waste. Due to the quenching effect of water and dependent upon the heat content of the waste, aqueous wastes are not capable of sustaining combustion if the aqueous component is greater than 75 percent of the total mixture [17]. These factors can be offset, however, if the waste is concentrated prior to firing or if fired in specially designed incinerators (see Table 3.4).

TABLE 3.4 TYPICAL AQUEOUS WASTE FIRED FOR HEAT RECOVERY [17]

Process type	Waste description		Btu/lb	Disposal
Adipic acid	Organic	13.8	1,494*	Incineration
	Inorganic	6.0		
	Water	90.2		
Synthetic cresol	Organic	15.0	1,646*	Incineration
	Inorganic	0.0		
	Water	85.0		
Drug intermediate	Organic	2.5	1,500*	Incineration
	Inorganic	12.0		
	Water	79.4		
Caprolactum	Organic	34.3	2,618	Incineration
	Inorganic	10.8		
	Water	54.9		
Sodium glutamate	Organic	12.2	4,515	Incineration
	Inorganic	24.2		
	Water	63.6		
Alcohol fermentation	Organic	36.0	3,573	Incineration
	Inorganic	9.0		
	Water	55.0		

*After concentration process.

Organic liquids are probably the best suited of all the potential waste fuels for industrial use. Typically these can consist of light solvents (toluene, benzene), still bottoms, lubricating oils, distillates (heavy hydrocarbons) or combinations of these liquids. Heating values generally lie in the Medium-Btu to High-Btu range; some can go as high as 46.52 MJ/kg (20,000 Btu/lb). Organic waste liquids with heat contents greater than 18.61 MJ/kg (8,000 Btu/lb) can sustain combustion in industrial applications without an auxiliary fuel. However, as the heat content of the waste declines, additional fuel may or may not be required, depending on the design characteristics of the individual boiler. Those wastes with heating values between 11.63-18.61 MJ/kg (5,000-8,000 Btu) are considered as partially combustible [18].

Hydrocarbons such as waste oil and waste solvent are the most likely candidates for industrial applications. Waste oils, however, are apt to contain contaminants which can pose environmental as well as combustion problems (see Table 3.5). Approximately two-thirds of the U.S. waste oil comes from the crank cases of automobiles and trucks and contains an estimated 1 percent by weight lead as well as other toxic materials [19].

Pretreatment prior to use is generally required since waste oils frequently contain sludge, grit, solvents, water, heavy metals, and additives

TABLE 3.5. CRANK CASE OIL CONTAMINANTS, ST. LOUIS AREA, 1970 [19]

Metal oxide	lb/10 ⁴ gal	Percent of total
Lead	650	56.1
Phosphorus (P)	189	16.3
Cadmium (Ca)	120	10.4
Silicon (Si)	64	5.5
Barium (Ba)	33	2.8
Iron (Fe)	32	2.8
Zinc (Zn)	32	2.8
Chromium (Cr)	2.2	-
Copper (Cu)	1.2	-
Antimony (Sn)	.9	-
Others	33.4	2.9
Total	1,158	

added during processing. Usually, however, this involves only the removal of water and solid particles by gravity settling and/or filtration [19].

Waste solvents are organic dissolving agents which have been contaminated with suspended and dissolved solids, organic matter, organometallics, or other solvents. Normally the contaminants compose less than 10 percent of the solvent. Industries that produce waste solvent include the drug industry, solvent refineries, vegetable oil extraction, polymerization processes, and cleaning operations. Fuels derived from these hydrocarbon solvents are markedly different from petroleum oil in chemical and physical properties. They differ in flow characteristics, air-fuel ratio required for combustion, pumping requirements, and injection pressure requirements in general. Since they have a lower viscosity than fuel oils, liquid hydrocarbon requires lower pressure for movement and atomization and this can therefore affect the feed rate. The heat content is also variable; and often, in order to achieve the temperature and steam pressures required for plant processes, waste hydrocarbon flow rates must be larger than those for oil [18].

The single largest group of solvents used in industry are halogenated solvents. Approximately 26 percent of the 205,000 metric tons of dirty solvent reclaimed in 1974 were either chlorinated or fluorinated solvent [19]. Physically these solvents tend to behave like their hydrocarbon counterparts; however, marked differences are seen in the heat contents (See Table 3.6). The heating value of these wastes decreases as the percent by weight of the halogen constituent increases. This has been attributed to the flame retardant effects of the halogen atom. For example, chlorinated compounds with a concentration greater than 70 percent by weight chlorine can require an auxiliary fuel source in order to sustain combustion [20].

The use of halogenated waste as fuel also presents problems with corrosion in the boiler and in the heat recovery devices. Care must be taken to maintain the combustion products which are rich in halogen acids above their respective dewpoints in order to prevent condensation and corrosion. This fixes the minimum temperature in the heat recovery devices and thereby determines the energy available for recovery. In addition, sufficient hydrogen must be provided usually in the form of an auxiliary fuel to permit the combustion of free halogen gases, such as chlorine gas, to their respective acids. Otherwise, stress corrosion problems can occur in the heat recovery units [13].

TABLE 3.6 REPRESENTATIVE SOLVENTS USED IN THE PHARMACEUTICAL INDUSTRY [21]

Type	Compound	Heat of combustion	
		MJ/kg	BTu/lb
Halogenated	Ethylene dichloride	8.0	3,425
	Chloroform	3.1	1,346
Nonhalogenated	Acetone	30.8	13,268
	Benzene	42.0	18,568
	Butanol	36.1	15,557
	Ethanol	31.0	13,340
	Isopropanol	33.10	14,259
	Methanol	23.8	10,266
	Toluene	42.9	18,468
	Naphtha	34.7	14,962
	n-Heptane	44.9	19,343
	Amyl-acetate	33.6	14,457

Hydrochloric acid that formed in the flue gas [22] of experimental burners using chlorinated solvent mixtures with a chlorine content between 0.1-5 percent by weight have damaged to the boiler refractories. The acid attacked the binders that made up the refractory, forming a salt that crumbled away undermining areas of the boilerplate. The problem was greatest when the chlorine content exceeded 1 percent by weight chlorine. Concentrations as high as 2000 ppm hydrochloric acid were measured in the flue gas [22].

Other categories of liquid waste with fuel potential include sulfonated hydrocarbons, phosphorylated hydrocarbons, and organometallics. Sulfonated hydrocarbons include solvents such as dimethyl sulfoxide (DMSO). When DMSO is burned, the sulfur forms sulfur dioxide and sulfur trioxide. Since water vapor is also a combustion product, condensation can cause sulfurous or sulfuric acid formation [23]. Temperatures in the system must be maintained several hundred degrees above the dewpoints of the sulfur acids. The same problem arises with the combustion of phosphorylated hydrocarbons. Phosphorous pentoxide (P_2O_5) is generated as a combustion product. It can condense with water vapor to produce a less severe corrosion problem [23].

Organic waste liquids also contain metals in the form of organometallics or inorganic salts in a aqueous component. These do not substantially affect the heat content of the waste but contribute to post-combustion problems. The

metallic salts often have a low melting temperature and can be deposited on heat transfer surfaces in a sticky, molten form that is difficult to remove. Metallic salts can also form eutectic mixtures which degrade metallic surfaces.

Solid waste is the final category of industrial waste with potential for energy recovery (see Table 3.7). In industrial situations, the solid waste component can be varied, but generally one class of constituents will predominate. It can consist of semisolid sludges and still bottoms too viscous to be handled as liquids or solid discrete objects such as rubber or plastic scraps [9].

Sludges and tars generally are the residue from chemical reactors. They vary in heat content, depending upon the individual process, the product, and the concentration of unreacted reactants (see Table 3.8).

TABLE 3.7 SOLID WASTES PRESENTLY BURNED IN INDUSTRIAL APPLICATION [15]

Waste	MJ/kg	(Btu/lb)
Polyethylene	45.4	(19,500)
Aldehyde sludge	42.2	(18,150)
Tire scrap	41.9	(18,000)
Polyvinyl chloride	40.7	(17,500)
Leather scrap	23.3	(10,000)
Composite industrial waste*	15.4-17.0	(6,600-7,300)
Bagasse	8.4-15.1	(3,600-6,500)
Wood bark	10.5-12.1	(4,500-5,200)
Industrial sludge*	8.6- 9.8	(3,700-4,200)
Wet garbage	4.7	(2,000)

*Composition not specified.

Still bottoms are the principal waste of the solvent reclamation industry. These still bottoms contain the debris picked up by the various solvents during their industrial application (see Tables 3.9 and 3.10). They vary in heat content, dependent upon composition.

Plastic wastes originate from both the synthetic and fabrication processes. These wastes consist of tars and still bottoms, off-spec product, or shavings and trimmings. Plastics have heat contents similar to high grade fuel oils (see Table 3.11).

TABLE 3.8 SOLID WASTE FROM THE CHEMICAL INDUSTRY [24]

Hazardous Waste Stream	Waste Stream Characteristics and Constituents	Physical Form	Heating Value
Rubber Manufacturing Waste Sludge	Solid waste containing SBR rubber (styrene-butadiene copolymer) and carbon black plus the usual salts, fatty acids, soaps, etc., from the coagulation of latex	Solid	Medium
Solid residue from manufacture of aromatic amines	Long-chain aromatic amines	Solid	Medium
Reactor tar bottoms from adiponitrile manufacture	Tars containing phosphoric acid (4.8 wt %) and adiponitrile	Solid	Medium
Acrylonitrile manufacturing wastes	Heavy ends containing acrylonitrile ($\text{CH}_2 = \text{CHCN}$), acetonitrile (CH_3CN), HCN and probably polymeric material	Tar	Medium
Organic chemical, capacitor, transformer production wastes containing PCBs and alpha methylstyrene	Waste containing PCBs and alpha methylstyrene, in capacitors	Solid	Medium

TABLE 3.9 SOLVENT RECLAMATION RESIDUE [25]

Oils	Metal fines
Greases	Dissolved metals
Waxes	Organics
Detergents	Vegetable fiber
Pigments	Resins

*Up to 50 percent unreclaimed solvent.

TABLE 3.10 ANALYSIS OF SLUDGE FROM SOLVENT RECLAMATION [25]

Parameter	Percent composition	Parameter	Percent composition
Aluminum	1.1	Sodium	0.20
Barium	2.0	Lead	3.3
Boron	0.02	Antimony	0.05
Calcium	0.29	Silicon	0.02
Cadmium	0.003	Tin	0.08
Cobalt	0.03	Strontium	0.05
Chromium	0.15		
Iron	2.7	Vanadium	0.03
Magnesium	2.7	Zinc	0.38
Manganese	0.007	Phosphorus	0.06
Molybdenum	0.06	Solvent	43.0

TABLE 3.11 HEAT VALUE OF PLASTIC WASTE [26]

Source	MJ/kg	(Btu/lb)
Waste from PVC reactor		
Residue	28.6	12,300
Liquid condensate	32.6	14,000
Off gas	46.5	20,000
PVC waste	23.0	9,900
High density polyethylene	43.5	18,700
Polystyrene	39.3	16,900

Burning characteristics vary from plastic to plastic, and combustion is accompanied by physical change such as charring, melting, or vaporizing. Polyolefins burn relatively easy and give off no toxic gases. They do tend to melt and run off the grates resulting in molten pools of plastic which burn under the grates. Polystyrene degrades at 482°C with high heat release that can lead to incomplete burning. Polyvinyl chlorides behave similarly to halogenated solvents. Although PVCs are high in heat content, the presence of the halogen atom retards flame and requires the use of an auxiliary fuel to sustain combustion. In addition, the high chlorine content can generate large quantities of hydrochloric acid or chlorine gas. It has been estimated that 50 lbs of hydrochloric acid is generated for every 100 lbs of PVC consumed [26].

3.3 Thermal Destruction Characteristics

The heat content, flammability limits, flash point, ignition, and auto-ignition temperature generally govern the choice of waste as a fuel and its blend with other fuel in an operating combustion system. Once injected into the combustion zone, the thermal destruction of a given material is determined by the available oxygen partial pressure, the combustion temperature (T_c) and the time spent at T_c . Another parameter that is difficult to characterize--but essential for complete combustion--is good mixing, or turbulence, of the fuel with the oxidant (air).

Gases and volatile hydrocarbons can be well mixed with air during injection through a burner nozzle, giving the most favorable situation for thorough combustion--the premixed flame. Usually additional air must be supplied to complete the combustion. With many liquids, all semisolids, and solids, however, premixing is not achieved. Even though air might be used (with or without steam) to atomize or disperse the fuel, there is still a region which is predominantly fuel, an external region that is oxidant-rich, and a boundary region in which the combustion reactions are occurring. This is the situation of a diffusion flame, so-called because the fuel and oxidant are transported by diffusion into the combustion region.

A lot of research work has been to determine the combustion characteristics of various organic materials. Work up to 1962 is summarized in Reference 27. EPA has sponsored research on the thermal destruction characteristics of several pesticides [28], and several PCBs and related compounds [29]. In order to get an accurate measure of the relationship between time, temperature, and amount of material decomposed, a "slug flow" narrow bore reactor was used. The material tested was injected in the vapor phase as a "slug." Figure 3.1 shows the effect of temperature on destruction of mirex, kepone, and p,p'-DDT at a residence time of 1 second. Similar plots for PCBs and related species are shown in Figures 3.2 and 3.3. The effect of residence time on destruction for several species at a fixed temperature (704°C) is shown in Figure 3.4.

Essentially the same technique has been used to determine the destruction characteristics of vinyl chloride, ethyl acetate, acrolein, and benzene [30]. Further work by these authors [31] has developed thermal oxidation kinetics for 15 compounds under conditions of large amounts of excess air to simulate fume oxidation conditions. These are given in Table 3.12 along with the temperature required for 99.9 percent reduction at residence time of 1 and 2 seconds under these conditions of high dilution.

When high enough temperatures for destruction are not achieved or maintained for a sufficient period of time if there is not sufficient oxygen present locally, the thermal cracking or organic compounds (pyrolysis) may be accompanied by synthesis of higher molecular weight compounds. For example, ethylene pyrolyzed between 480° and 588°C yields propane, butene, butadiene, ethane, acetylene, and hydrogen [27,28]. Higher olefins or diolefins may form

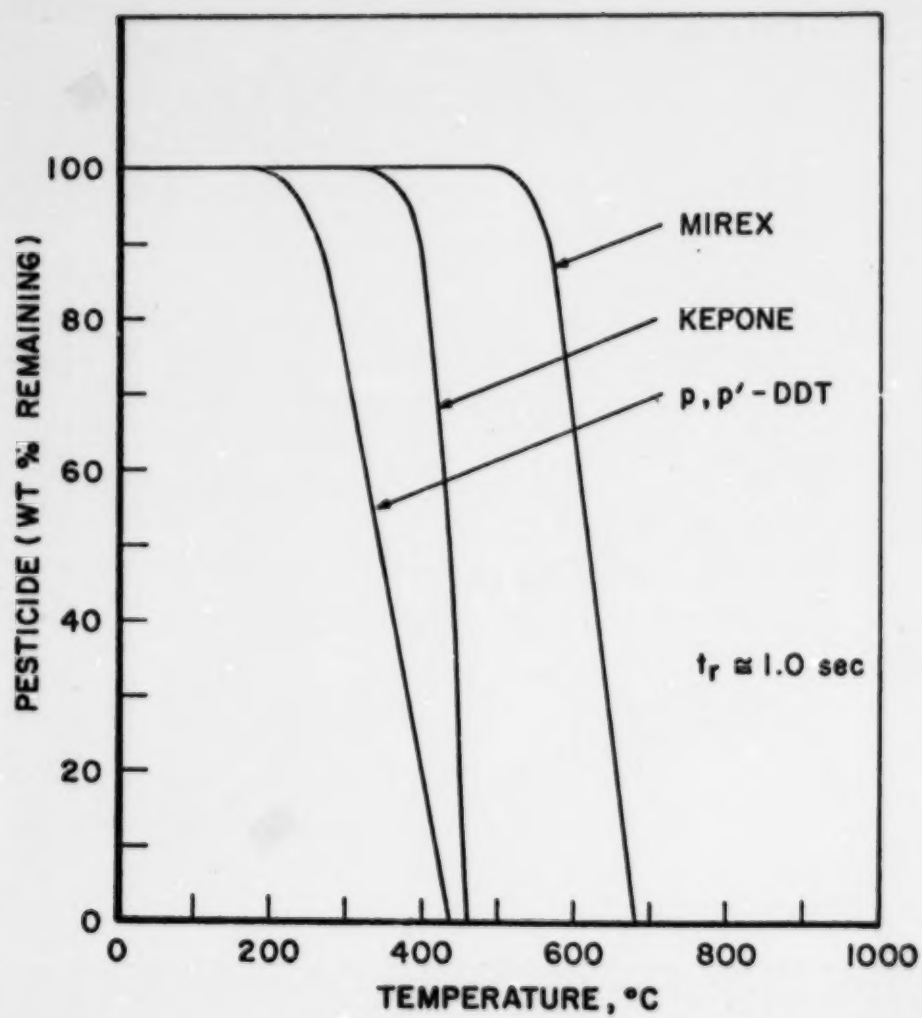


Figure 3.1. Comparison of thermal destruction of three pesticides [30]

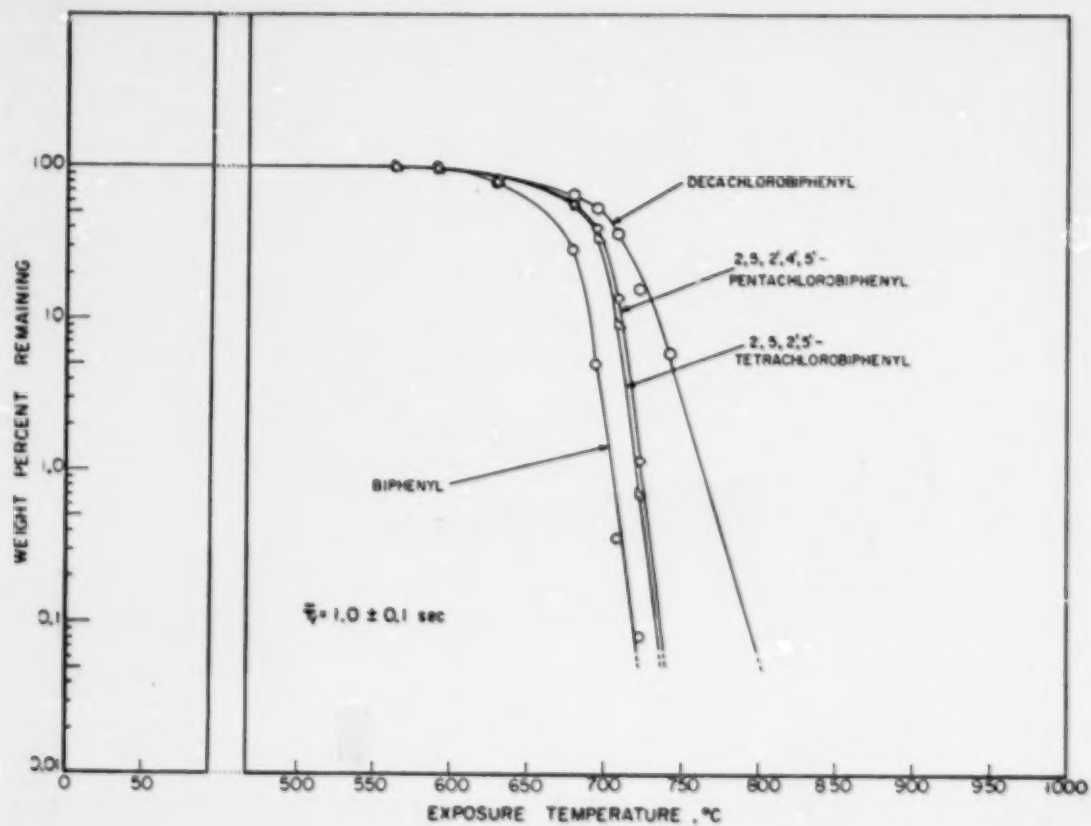


Figure 3.2 Thermal destruction profiles [30]

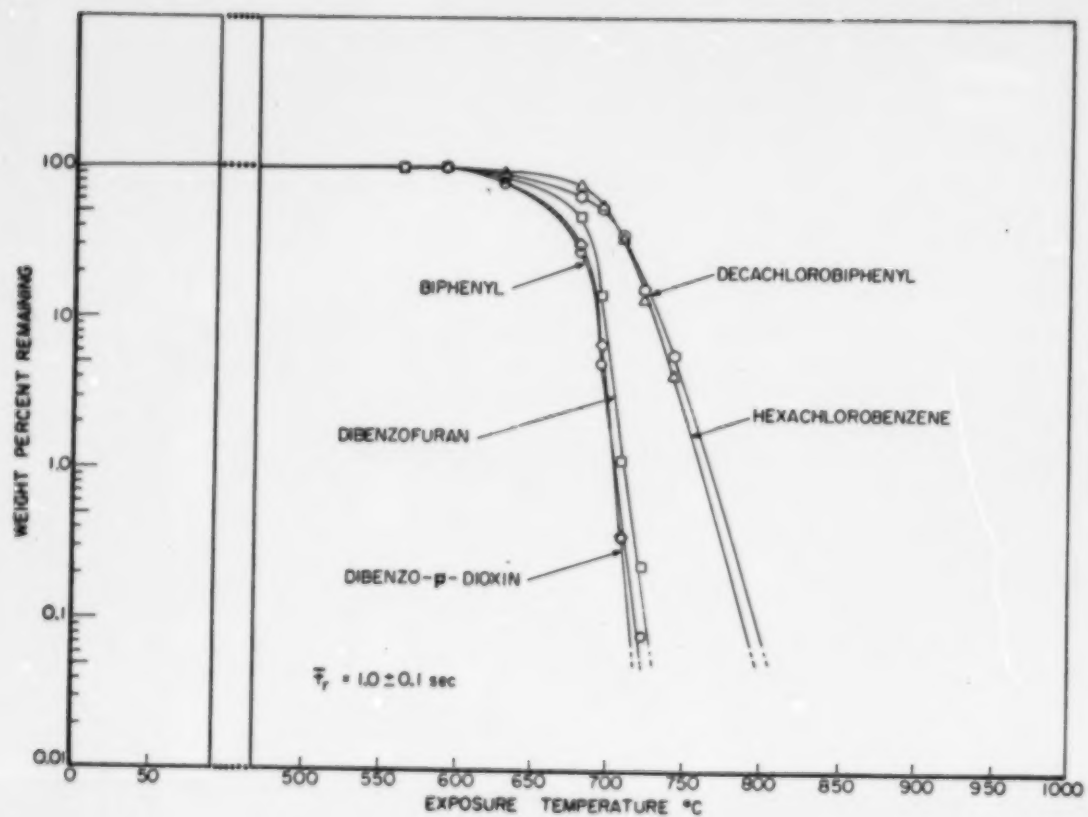


Figure 3.3. Thermal destruction profiles for individual compounds in the combined samples[30]

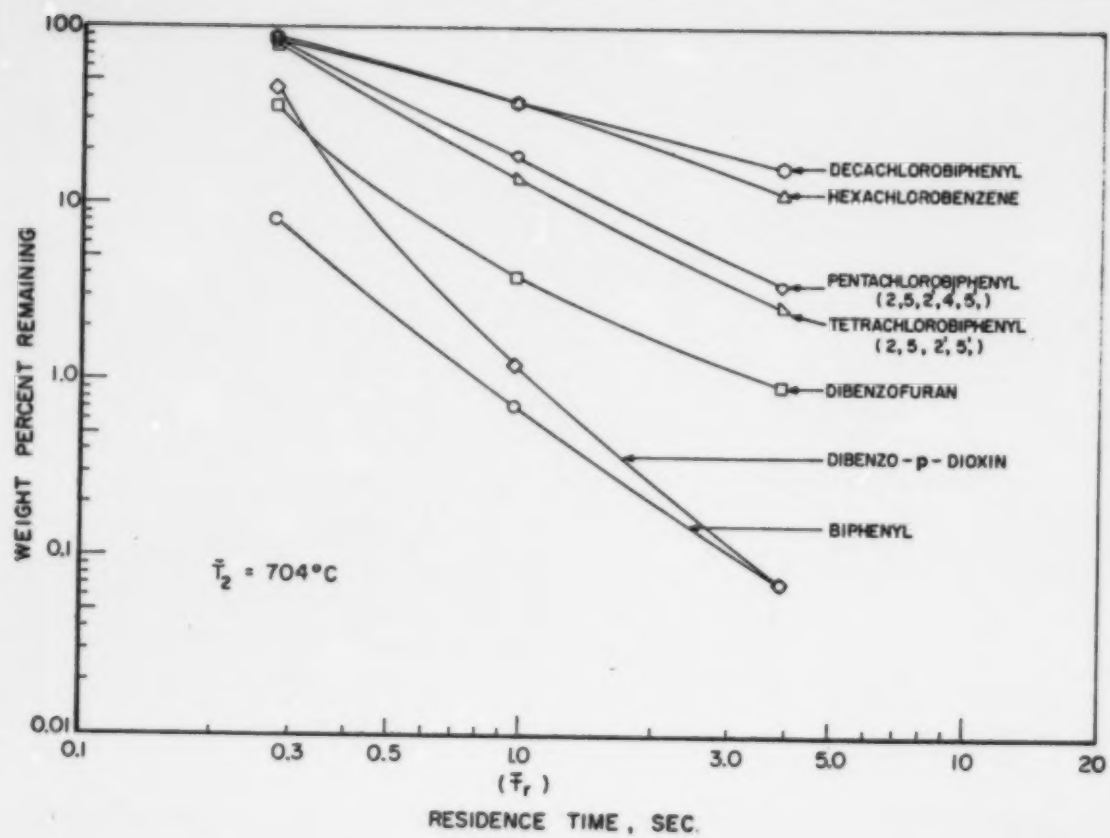


Figure 3.4. Effect of residence time at 704°C [30]

TABLE 3.12 CALCULATED DESTRUCTION TEMPERATURE FOR SELECTED COMPOUNDS [31]

Compound	Calculated destruction temperature	
	99.99 at 1 sec. (°F)	99.99 at 2 sec. (°F)
Methane	1542	1483
Ethane	1368	1326
Propane	1328	1298
Ethylene	1323	1278
Propylene	1318	1246
Butene	1231	1197
Benzene	1350	1321
Toluene	1337	1292
Acrolein	1018	973
Ethanol	1306	1256
Ethyl acrylate	1131	1090
Acrylonitrile	1342	1296
Triethylamine	1101	1059
Vinyl chloride	1373	1333
1,2-Dichloroethane	1214	1174

aromatic hydrocarbons. Even in the presence of oxygen, pesticides have been observed to form pyrolysis products [29].

Therefore it is probable that, unless a uniformly high temperature is maintained along with a plentiful supply of air in the region where the waste is being injected, additional chemical species can be created as air pollutants.

3.4 Industrial Use Patterns

The use of waste gas as a fuel source has generally been limited to high volume, medium Btu processes such as is found in coking operations, blast furnaces, or refineries. However, as emission levels are established for other gases, it is conceivable that the use of waste gases as a fuel source will spread to include low-Btu gases.

As a requirement of the Clean Air Act as amended, several States are currently revising their State Implementation Plans. The revisions include proposals to apply RACT (Reasonably Available Control Technology) to the control of volatile organic compounds (VOC) emissions from major VOC sources. The largest source of these emissions, comprising approximately 56 percent of the total, are those arising from solvent evaporative sources [32] (see Table 3.13). Approximately 1.3 million metric tons of these VOC, resulting from degreasing and surface coating operations, might be controlled by more efficient usage or add-on control devices [32]. The cost of these measures might be the incentive to use other disposal methods.

TABLE 3.13 SOURCES OF SOLVENTS EMISSIONS [32]

Source	Estimated VOC emissions 10 ³ metric tons/yr
Surface coating applications	1,753
Dry cleaning	227
Degreasing	836
Cutback asphalt	470
Graphic arts	240
Adhesives	481
Other solvent uses	3,000
Total	7,007

TABLE 3.14 WASTE OIL INVENTORY [34]

<u>Waste generation</u>	<u>10⁶ gallons</u>
Automotive lubricating oil	616
Industrial and aviation lubricating oil	394
Other industrial oil	87
U.S. Government lubricating oil	18
Marine oil, transportation losses, oil spills	209
Other oil losses in production and transportation*	<u>1,156</u>
Total	2,480
Oil and fat industry losses	13
Coke oven oil losses	<u>6</u>
Total generated	2,499
<u>Ultimate disposal</u>	<u>10⁶ gallons</u>
Directly to environment	978
Processing waste to environment	72
Road oil dust control	<u>281</u>
Subtotal environment	1,331
Directly for use as fuels	358
Used for processing plant fuels	49
Fuels sold by oil processors	<u>621</u>
Subtotal fuels	1,028
Road oil and dust control, lost by biodegradation	38
Re-refined oil sales	<u>83</u>
Subtotal other	121
Unknown	<u>19</u>
Total disposal	2,499

*Not included in 1.4 billion gallon estimate.

Due to the low heating values of these solvent-air mixtures (1-20 Btu/ft³), it is generally more economical to provide heat for associated drying operations by firing conventional fuels [33]. However, if these low-Btu mixtures contain at least 16 percent oxygen, they can be injected into the combustion systems down stream of the burner and used as makeup air. In this manner, it is possible to dispose of the vapors and get some measure of heat in return.

The use of waste liquids as a fuel source by industry is an established practice. It is estimated that the United States will generate approximately 1.4 billion gallons of waste oil in 1980. Due to the diversity of usage, a significant quantity of this waste will disappear from sight, but a large portion is used as fuel [34] (see Table 3.14). The waste may be blended with virgin oil or solvents and burned on site or recycled by a reclamation firm and a portion sold as fuel (see Figure 3.5). It is not uncommon for smaller plants to burn 100 percent reclaimed oil.

Solvents are also used as fuel. However, it is more difficult to establish an estimate of the quantity used. Consumption of virgin solvent by industry is estimated to be on the order of 4.7 million metric tons annually [32]. A substantial portion is consumed by the process or lost by evaporation. The end use of the recovered fraction is typified by the degreasing industry [32] (see Table 3.15).

TABLE 3.15 END USE OF SOLVENT WASTE GENERATED BY DEGREASING OPERATIONS [32]

Used Solvent Destination	Percent of Used Solvent Handled
Dumping, open storage containers, municipal or chemical landfills, and deep well injection	35
Mixed with waste crankcase oil by waste collector	15
Properly controlled incineration	5
Reclamation	45

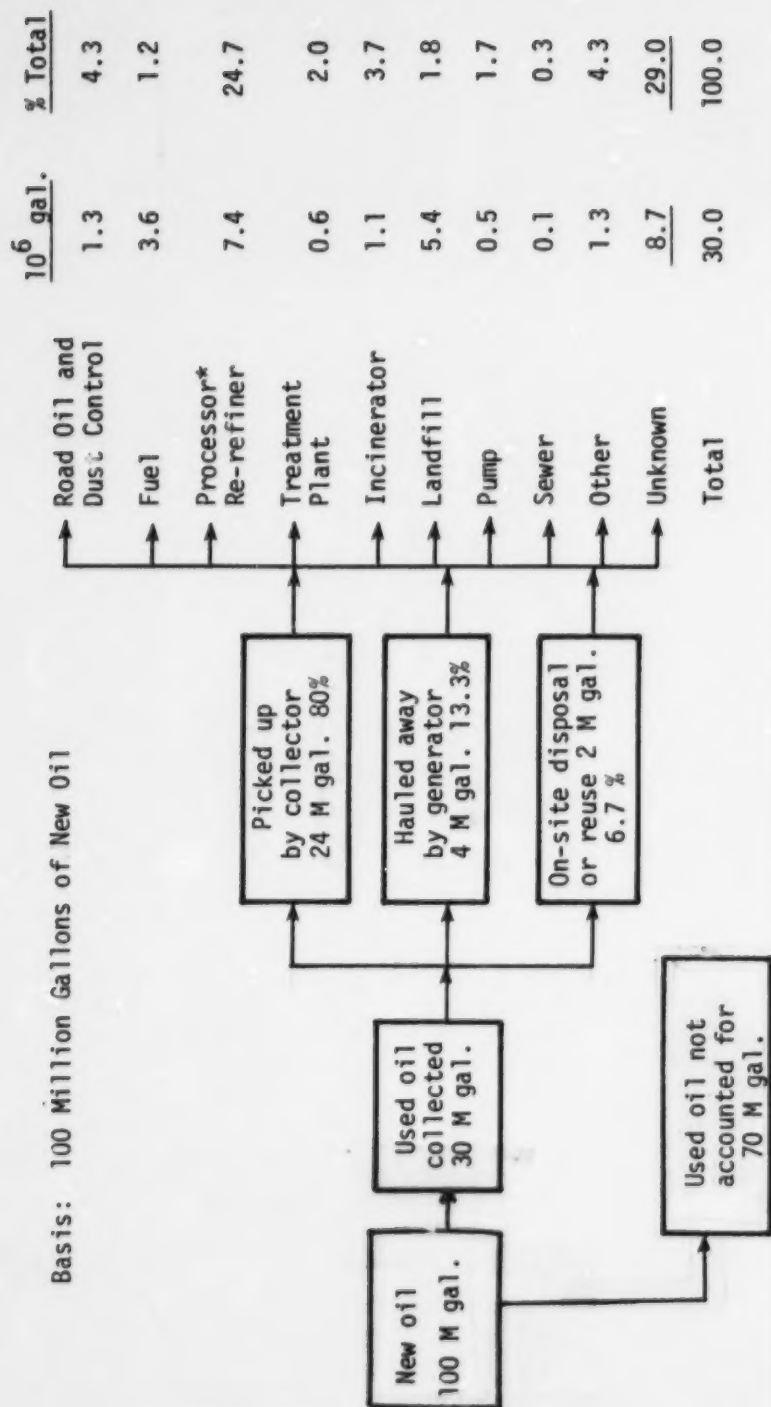


Figure 3.5. Typical disposal and reuse pattern for industrial used oil [32].

Overall reclamation is thought to be less than 45 percent of the total amount used. Based on the records of approximately 100 reclamation plants, it has been estimated that approximately 2.8×10^5 metric tons of spent solvent are recovered. These feed stocks arise from pharmaceutical firms, chemical processing, solvent manufacturing and distribution, metal cleaning and cooling, resin manufacturing, dry cleaning, paint manufacturing, factory-applied coating operations, vapor degreasing, and industrial printing [21].

It has been estimated that 4.5×10^4 metric tons of waste are in turn generated by the solvent reclamation industry in the reclamation of these solvents [21]. The wastes contain high percentages of solvents and have potential as a fuel source. Fourteen percent of these wastes are landfilled, and 86 percent are incinerated [21].

Recycling is a normal procedure for the plastic products industry. Off-spec products are sold to reclamation industries which blend them for resale to the industry. Thermoset plastics, however, cannot be recycled for refabrication and are prime candidates for industrial fuel use.

Waste rubber tires also have industrial applications. In 1971, 240-250 million tires were taken out of service. Of this, 46 million were retreaded, 7 million consumed through rubber reclamation, and 2 million were used by tire splitters. The remaining 185-200 million tires were abandoned or buried in landfills [34,35]. A small number have been shredded and used as a binder in asphalt or cofired in boilers [35]. Table 3.16 compares the heat content of rubber and coals.

Waste wood also has fuel potential. It has been estimated that in the United States 2-3 quads of wood waste are available for fuel [36]. Wood varies in physical properties and is typically low in sulfur. The heat content is variable but typically is around 11.6 MJ/kg (5,000 Btu/lb). It has been burned in a blend with coal. Problems encountered included ignition outside the furnace and a variable moisture content which has caused problems with firing [36].

TABLE 3.16 PROXIMATE ANALYSIS OF WASTE TIRES VS. COAL [35]

	M	Fired carbon	Volatile matter	Ash	Sulfur	Btu/lb
Tire tread	.9	29.2	66.5	3.4	1.04	16,287
Tire fabric	2.8	15.3	80.0	1.9	1.04	11,846
Anthracite	2.5	79.4	6.2	11.9	0.6	12,925
Bituminous						
W.VA	1.0	77.3	18.6	5.1	0.7	14,715
PA	1.5	64.9	23.4	10.2	2.2	13,800
KY	2.5	57.5	36.7	3.3	0.7	14,480
OH	3.6	47.3	40.0	9.1	4.0	12,850
Lignite	37.0	26.6	26.6	4.2	0.4	7,255

4.0 INVENTORIES

The quantities of various organic materials suitable for energy recovery have been estimated in a series of Federal and State studies over the past several years. These efforts have ranged from surveys of production and sales data through extrapolations based on the response to telephone surveys and questionnaires by a relatively small number of firms to in-depth surveys and site visits. Although the "error bars" for more in-depth studies should be much smaller, there is still much uncertainty about the ultimate disposal fate of many of the organic materials used or generated by industry. In this section, a brief overview of some of the existing reports with inventory data is given.

4.1 Data From Federal Studies

A series of overview studies "Assessment of Industrial Waste Practices--(industry)" were conducted by the Office of Solid Waste in the mid-70's [37]. Types of material generated were specified and the quantities estimated. Technology for treatment and disposal of waste streams was also surveyed.

Information developed in these assessments has been subsequently used in further EPA studies of the issue of energy recovery from waste burning. Reynolds, Smith and Hill (RSH) [21] conducted an engineering study for OSW on the energy conversion potential of industrial waste streams. Using the generation of low pressure (125 psi) steam as the selected energy recovery medium and defining a heat content of 18.4 MJ/kg (about 8,000 Btu/lb) as the threshold for practical recovery, this study identified five industrial categories as having sufficient waste heat potential to justify more detailed study on methods of implementation. These are identified in Table 4.1 along with the quantities of waste estimated to be burnable for energy recovery.

Several conclusions of the RSH report, in addition to the inventory data, are that such combustion is:

1. Justifiable only on a site-specific basis;
2. Generally not reliable enough as a sole energy source;
3. Potentially hazardous due to incomplete combustion or the generation of toxic gases or vapors;
4. Possibly restrained by the amount of capital required for heating and pollution control equipment.

These conclusions are discussed further in subsequent sections.

TABLE 4.1. QUANTITIES OF WASTE FROM VARIOUS INDUSTRIES
ESTIMATED FOR ENERGY RECOVERY [21]

Industry	Total annual hazardous (combustible) waste, metric tons	Waste heat utility	Potential for further study
Organic chemicals	1,500,000	Yes	Good
Plastics	445,000	Yes	Good
Petroleum refining	110,000	Yes	Good
Drugs	65,000	Yes	Good
Tires	31,000	Yes	Good

A recently completed study by ETA Engineering for IERL-Cincinnati compiled an inventory of used and byproduct hydrocarbon streams [32]. Included were volatile organic constituents (VOCs), waste oils, and solvents. Semi-solids, sludges, and solids were not included. This study concluded that petroleum refineries were the only major industry with substantial recovery potential for VOCs, with an estimated 8.9×10^5 metric tons/year recoverable. Using data from previous reports, the study estimated that about 2.8×10^9 liters/year of automotive lubricating oils and 5.4×10^9 liters of industrial oils (of various types) were generated in 1977. The energy content of these oils ranges from 31.5 to 44.7 MJ/kg (13,000 to 19,300 Btu/lb) [32]. The ultimate fate of most of this oil is not known (see Figure 3.11). Many States, as will be discussed in Section 4.2, have undertaken surveys to determine disposal practices, but much is yet to be learned before an accurate inventory can be obtained.

The ETA report used data from a commercial industry newspaper to estimate 1978 demand for solvents in the categories of halogenated hydrocarbons, ketones, and alcohols. Cumulative demands were estimated to be 1.39M metric tons/year of halogenated hydrocarbons, 1.45M metric tons/year of ketones, and

1.53M metric tons/year of alcohols. The total is about 4.37M metric tons/year [32]. A previous EPA source assessment of the solvent reclaiming industry has estimated that about 0.1M metric tons/year of solvent are reclaimed, or a little over 2 percent [25].

A more recent EPA study [38] estimated a total industrial use of 5.53M metric tons/year of solvents by industry. One reason for the discrepancy on total solvent usage between this study and that cited previously [32] is the inclusion of another solvent category "special naphthas" and various other solvents that were not included in the ETA study which was limited to only those materials which did not undergo chemical modification during use, whereas the more recent [38] study included specifically materials which could undergo change. Both studies did provide breakdown estimates of the solvent quantities used by various industrial categories. An example is shown in Table 4.2.

4.2 Data From State Studies

Many States have carried out a survey to determine the types, rates of generation, and disposition of hazardous wastes within their jurisdiction. The data from these surveys are useful in understanding the patterns that recently existed. How these patterns might change under the impetus of new hazardous waste disposal regulations is unknown. As might be expected, the units used and the degree of detail vary considerably from State to State. There are also considerable differences in the reported details of disposal practice. Some of these surveys are sketched below.

Table 4.3 indicates the volume of waste organics generated in Oregon in 1972-1973. It should be noted that not all of the "other chemicals" were organic compounds. These data are extrapolations from data obtained by onsite visits or other contacts with 110 firms in Oregon. Table 4.4 shows the hazardous waste inventory for the State of Massachusetts in 1976. This breakdown is not by industry/nonindustry categorization for the sources. The data come from permits issued to waste handlers. It should be noted that there is generally a discrepancy between the "collected" figure and the sum of the disposal method quantities for each type of waste in Table 4.4. The waste handlers reported that more material was collected than delivered, with the exception of solid sludges. It could well be that some of these sludges

TABLE 4.2 CLASSIFICATION OF SOLVENT END USES INTO INDUSTRIAL AND CONSUMER/COMMERCIAL USAGE SECTORS [38]

Industrial uses	Nationwide consumption	
	metric tons/yr	lbs x 10 ⁶ /yr
	5.534	12,200
Industrial surface coatings	1.820	4,000
Metal cleaning	.660	1,449
Adhesives, Industrial use	.465	1,020
Industrial processes	.380	836
Dry cleaning	.290	638
Plastics	.280	621
Graphic arts	.270	595
Rubber	.210	455
Resins	.210	454
Textiles	.180	400
Extraction vegetable oil	.160	342
Auto body refinishing	.160	352
Paint removing	.075	165
Cleaning	.074	162
Acetaldehyde process	.071	157
Cellulose acetate solvent	.046	102
Pharmaceutical industry	.029	64
Lube oil refining	.025	54
Phillips low pressure polyethylene solvent	.018	39
Extraction hardwood pulping	.015	33
Electrolytic solvent in Grignard reaction	.015	33
Inks	.015	32
Foal Blowing	.013	28
Extraction, Udex	.012	26
Extraction solvent	.011	25
Toluene diisocyanate process	.010	23
Solvent for acetylene	.010	21
Extraction, butadiene	.005	11
Extraction, rare metals	.005	10

TABLE 4.3 VOLUMES OF WASTE (m³/yr) GENERATED IN THE
STATE OF OREGON, 1972-1973 [39]

Source	Pesticides	Solvents/oils	Other chemicals
Industrial	410	8,292	16,783
Automotive	-	30,281	-
Totals	410	38,573	16,783

*Not all organics.

TABLE 4.4 VOLUMES OF WASTE (m³/yr) GENERATED IN THE
STATE OF MASSACHUSETTS IN 1976 [40].

Waste	Collected	Reclaimed	Burned	Landfill	Other*
Oil	50,454	11,529	26,180	1,893	8,330
Solvents	9,841	5,844	844	129	68
Aqueous liquids	7,570	-	-	38	6,953
Solids and sludges	3,157	-	2,800	3,785	208
Other	545	-	295	254	-
TOTALS	71,612	17,373	30,121	6,132	15,559

*Dust control, asphalt plants, wastewater treatment, etc.

settle out of the oils, solvents, and aqueous liquids in storage and transit. Disposal will be discussed in Section 6. The State of Massachusetts maintains a current update of the inventory, which can be made accessible for further EPA research [40].

The State of New York has conducted an extensive survey [41] contacting some 1,170 generators out of an estimated 4,000. The response rate of the firms contacted was at better than 90 percent. The total of 1.0×10^6 metric tons/year of waste accounted for in the survey was estimated to represent 90 percent of that actually generated in New York. Six groups of industries in the State account for more than three-quarters of the annual hazardous waste production: organic and inorganic chemicals, primary metals, plastics, petroleum refining, and pharmaceuticals. The New York survey provides an in-depth view of the types of waste generated by the various industries in the State and how these materials are disposed of. Table 4.5 provides a summary.

The State of North Carolina conducted a survey of hazardous waste generation in the State in 1978 and collected data by site visits to selected facilities representative of the major industries of the State. The types of detail available on the hazardous wastes generated by various industries are illustrated by the listing given in Table 4.6 for the textile industry in North Carolina [42].

The State of Illinois has also conducted a thorough survey of industrial waste generation and disposal practices [43]. Out of 21,000 industrial establishments queried, 7,900 responded. These represented 62 percent of the industrial employees in Illinois. Table 4.7 provides an overview of waste types and disposal locations for these materials.

The State of California is in the process of conducting an inventory of its hazardous wastes [44]. The State of Maryland has also recently instituted procedures to collect similar data [45].

TABLE 4.5 MAJOR VOLUMES OF HAZARDOUS WASTES BY TYPE IN NEW YORK STATE

Type	Approximate hazardous waste generation (m ³)
1. Acids	71,915
2. Alkalies	9,084
3. Pickle liquor	55,261
4. Etching solution	4,164
5. Halogenated solvents	3,785
6. Other solvents	191,900
7. Heavy metal sludges	54,883
8. Wastewater treatment sludges	198,334
9. Other sludges	62,831
10. Waste oils	59,425
11. Still bottoms	12,491
12. Photographic chemicals	7,192
13. Rinse water and other wastewaters	<u>86,677</u>
	817,938
Use 1.2 metric tons/m ³ for conversion to tons	
14. Leather tanning wastes	982,272 metric tons subtotal
	<u>27,223</u> metric tons subtotal
Grand total	1,009,495 metric tons

TABLE 4.6. LISTING OF TYPES AND QUANTITIES OF HAZARDOUS WASTES GENERATED
BY THE TEXTILE INDUSTRY (SIC-22) IN NORTH CAROLINA [42]

Type of waste	Quantity in gallons	Percent of total quantity
Sanitary and dyehouse waste treatment sludge	651,700	82.8
Varsol type solvents	59,270	7.5
Lubricating and hydraulic oils	31,995	4.0
Latex sludge	16,775	2.1
Acrylic foam	10,843	1.3
Glyoxal resin	6,500	0.8
Starch	5,000	0.6
Concentrated dye sludge	2,250	0.3
Paraffin and oil sludge	600	0.07
Resin sludge	330	0.04
Chlorinated hydrocarbon solvents	100	0.01
Total	786,598	

TABLE 4.7. DISPOSAL LOCATIONS FOR PROJECTED WASTES
FROM ILLINOIS INDUSTRY [43]

Type of waste	On-site		Off-site, within Illinois		Off-site, out of state		Off-site, location unspecified	
	(tons) ^a	(gals) ^a	(tons) ^a	(gals) ^a	(tons) ^a	(gals) ^a	(tons) ^a	(gals) ^a
Oil	46,484	5,514,932	12,805	7,798,764	0	28,621,246	1	2,961,422
Solvents - low flash point	59,906	2,834,149	68	3,345,132	622	1,598,825	5	2,662,655
Solvents - chlorinated	15,254	81,012	68	657,847	7,390	1,609,611	0	539,456
Solvents, nonchlorinated	0	222,278	546	788,898	440	225,468	136	1,091,451
Aqueous liquids	22,473	7,951,038	610	14,713,639	8,850	293,816	0	2,636,567
Metal-containing liquids	0	27,069,545	12,477	91,048,286	16	2,402,943	465	11,396,893
Cyanide and metal liquids	0	618,505	0	152,268	0	53,196	0	40,126,789
Other inorganic liquids	115,203	452,464,290	803	16,883,778	0	11,984,761	0	993,066
Oil sludge	26,493	2,440,063	96,228	6,235,427	0	263,498	30	3,744,535
Contam. clay filter, sand	6,405	4,449,860	58,107	13,858,647	407	0	352	3,611,093
Dye and paint sludges	10,929	39,891	4,870	9,088,810	2	867,123	52	520,752
Fats and waxes	88	180,919	354	1,384,985	3	87,811	37	127,428
Resin, latex, monomer	0	7,632,304	4,977	9,390,147	602	9,673	20	6,282,847
Chlorinated organic sludge	0	842,522	141	155,622	3	10,126	0	630
Nonchlorinated organic sludge	23,123	1,557,990	19,363	92,390,160	0	0	10	1,875,606
Metal-containing sludge	151,438	5,489,361	92,016	28,279,914	127,905	1,473,621	1,063	1,506,328
Metal and cyanide sludge	26,008	778,757	354	2,458,555	56,039	72,078	289	189,940
Other inorganic sludge	3,174,743	222,961,559	130,414	16,350,912	13	123,567	47,988	1,861,753
Metallic dusts	37,767	69,985	89,539	10,704,640	25,168	847	14,888	557,628
Nonmetallic inorganic dust	990,208	67,716,080	578,411	115,733,416	21,253	0	178,779	649,172
Chlorinated organic solids	0	83,472	2,189	5,191,678	0	0	160	2,813,660
Nonchlorinated organic solids	16,354	8,310,754	36,573	34,659,835	885	0	2,651	545,378
Pesticides, herbicides	<1	4,686	418	10,367	0	1,293	330	2,112
PCB ^b	0	4,549	0	1,468	6	43,153	45	10,027
Explosive	1,226	928	<1	0	0	0	251	0
Asbestos	0	34,409	46	250,361	275	1,717,512	2	0
Other	7,035,300	32	743,945	28,502,631	155	71,291	2,408	26,085,019
State Totals	11,759,506	819,353,870	1,885,322	510,036,187	250,035	51,531,459	249,958	112,792,407

^aWaste quantities of gallons and tons are additive.

5.0 COMBUSTION TECHNOLOGY

In 1977, there were approximately 1,800,000 nonutility boilers in place in the United States. Less than 1 percent of these boilers exceeded the New Source Performance Standards (NSPS) size limitation of 73.3 MW thermal, but those that did exceed the NSPS constituted 17 percent of the installed capacity (see Table 5.1).

5.1 Industrial Boiler Population

Boilers can be classified in many ways, such as by boiler type, method of manufacture, and fuel use. One such scheme utilizing these criteria is shown in Figure 5.1.

From this scheme, it can be seen that there are three major types of boilers or heat transfer configurations: water-tube, fire-tube, and cast iron. Each type of boiler is suited to specific applications and sites. Water-tube boilers are used in a variety of applications ranging from supplying large amounts of process steam to providing space heat for industrial and commercial facilities. Fire-tube boilers are not available with capacities as large as those of water-tube boilers, but they also are used in a variety of applications such as for supplying process steam and for space heating. Cast iron boilers are limited in size and are used only for supplying space heat. A distribution of boilers based on the heat transfer configuration is shown in Table 5.2. Detailed descriptions of the various designs in these categories are given in Reference 46. About 72 percent of the present boiler population is in the commercial sector; the remaining 28 percent have industrial applications (see Table 5.3).

Although the number of commercial boilers is greater than twice that of industrial boilers, the latter's generating capacity comprises 69 percent of the total for the industrial/commercial sector.

The major fuels consumed by industrial and commercial boilers are coal, residual oil, natural gas, and distillate oil. These four fuels constitute greater than 90 percent of all the fuels consumed in the commercial/industrial sector. Natural gas is the predominant fuel accounting for 45 percent of the total capacity. Residual oil is second at 27 percent, coal comprises 18 percent, and distillate oil is at 10 percent (see Table 5.4).

TABLE 5.1. DISTRIBUTION OF COMMERCIAL/INDUSTRIAL BOILERS BY SIZE

Size MW thermal (10^6 Btu/hr)	Number of boilers	Total capacity	
		MW thermal	(10^6 Btu/hr)
Equal to or under 0.1 (equal to or under 0.4)	970,980	69,180	(236,100)
Over 0.1 to 0.4 (over 0.4 to 1.5)	568,415	143,820	(490,700)
Over 0.4 to 2.9 (over 1.5 to 10)	208,659	240,270	(820,000)
Over 2.9 to 7.3 (over 10 to 25)	25,081	126,770	(432,600)
Over 7.3 to 14.7 (over 25 to 50)	16,483	178,350	(608,700)
Over 14.7 to 29.3 (over 50 to 100)	6,840	147,380	(503,000)
Over 29.3 to 73.3 (over 100 to 250)	4,266	185,160	(632,000)
Over 73.3 to 146.5 (over 250 to 500)	1,018	98,280	(335,400)
Over 146.5 to 439.5 (over 500 to 1,500)	253	56,080	(191,400)
Over 439.5 (over 1,500)	65	68,050	(232,200)

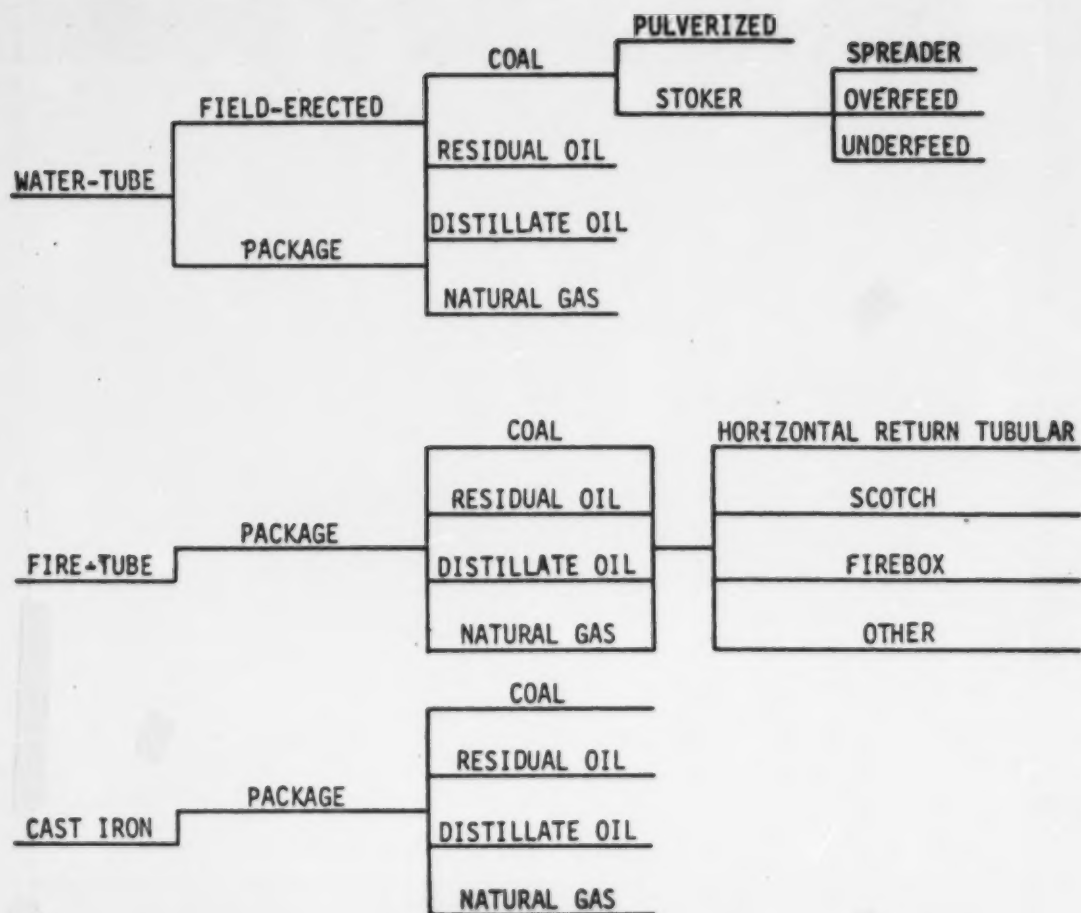


Figure 5.1 Possible combinations of characteristics associated with U.S. industrial/commercial boilers

Industrial boilers are concentrated into four major industries: (1) pulp and paper, (2) primary metals, (3) chemicals, and (4) minerals. Of the three types available, water-tube boilers predominate in industry. Approximately three-quarters of these units are package units. However, since the field-erected water-tube boilers are generally larger, they supply more than 50 per cent of the total capacity for industry.

TABLE 5.2 BOILER POPULATION DISTRIBUTED BY HEAT TRANSFER CONFIGURATION [46]

Heat transfer configuration	Number of boilers	Total capacity	
		MW thermal	10^6 Btu/hr
Water-tube	50,495	747,930	(2,552,500)
Fire-tube	275,075	302,780	(1,033,300)
Cast iron	1,476,490	262,600	(896,200)

TABLE 5.3 DISTRIBUTION OF NONUTILITY BOILERS BY SECTORS [46]

Sector	Number of boilers	Total capacity	
		MW thermal	(10^6 Btu/hr)
Commercial	1,295,130	402,780	(1,374,690)
Industrial	506,930	910,480	(3,107,440)

TABLE 5.4 SUMMARY OF THE TOTAL BOILER POPULATION BY FUEL USED [46]

Fuel	Number of boilers	Total capacity	
		MW thermal	(10^6 Btu/hr)
Coal	214,400	239,110	(815,830)
Residual oil	389,104	358,570	(1,223,800)
Distillate oil	244,206	127,040	(433,600)
Natural gas	954,350	588,590	(2,008,800)

In addition to the potential for being affected by environmental regulations, new boilers with heat inputs greater than 29.3 MW thermal will be subjected to the DOE conversion strategy for new boilers. This strategy seeks to restrict the use of natural gas and oil by prohibiting the burning of fuels other than coal, coal-derived liquids, and refuse-derived fuels without prior DOE critical review and approval. Mandatory coal usage may well change the distribution of fuels fired in large industrial boilers by the year 2000. However, the immediate emphasis is placed on the burning of more natural gas and phasing out of oil [46].

5.2 Typical Combustion Conditions

It is difficult, if not impossible, to address typical combustion conditions in industrial boilers. Combustion conditions vary from boiler to boiler and from day to day depending upon the operational needs of a given plant. It is possible, however, to relate temperature and residence time when attempting to address typical conditions, but the mixing aspects of each combustion system, the quantity of excess air, the fuel type, and consequently the combustion products will vary from unit to unit.

The crucial factor in achieving high combustion efficiency is turbulence and the mixing of the potential reactants. This feature is incorporated into the design of each boiler and is generally attained by aerodynamic or mechanical means. The design, however, is based on a preselected fuel type and feed rate and may be far from optimum for the efficient combustion of a waste fuel.

5.3 Burner Design and Operation in Cofiring

The type of combustion equipment varies with the type of feed. Generally, a liquid or gas incinerator will be a refractory-lined furnace or retort designed to mix air and/or oxygen in quantities which will affect complete combustion and provide the residence time sufficient to complete the reaction in the incineration. If a fuel will not burn alone, then auxiliary fuel will be required. Usually, this is supplied by auxiliary burners firing into the same chamber into which the waste is sprayed, and sufficient excess air to combust the waste material must enter either through the burner or through ports in the chamber. High temperature products of combustion are then ready for heat recovery of some type or other.

In general, if a waste gas is available in steady supply and constitutes at least 50 percent of the total fuel value, it can be burned in conventional industrial burner systems of the forced air and/or induced draft varieties. The fuel can be injected into the burner, mixed with sufficient air to achieve complete combustion, and burned [47].

If the calorific value of the gas decreases or fluctuates, the gas can be burned in an independently heated, refractory-lined afterburner. This can occur at temperatures between 700° and 900°C in the presence of a flame. Natural gas or some other auxiliary fuel may be used to preheat the chamber. The gaseous combustion product can then be passed through a heat exchange device for energy recovery [47].

Controls are essential to stable burner operation. If the controls are to function properly, there must be a stable fuel supply with regards to pressure and calorific value.

When conventional gas burners of the sealed-pit type are used to burn waste, the variation in the calorific value of the fuel cannot exceed 10 percent if there is to be an adequate air supply for combustion. If the burners are designed for 100-percent premix operations, but with provisions for the entry of secondary air based on 10-percent excess air with the lowest calorific gas, they can accept variations in calorific value by as much as 40-50 percent. Other premixed burner configurations designed for greater quantities of secondary air can accept and burn gases where the heating values vary as much as 150 percent [13].

Maximum pressure is particularly important to stable operations in situations where a wide range of calorific values can occur. This is because burner equipment must be designed for maximum heat release with the lowest calorific value gas at the maximum pressure available. If the calorific value rises, fewer standard cubic feet of gas are required for heat release, and the pressure will fall. If the drop is too great or fluctuates, the burner performance falls off severely [13].

In general, waste liquid cannot be oxidized efficiently in conventional burners. Special configurations have been designed to introduce waste through a nozzle at the center line of the burner. Combustion air is brought in tangentially and passes through swirl vanes which impart rotational energy.

The vortex action results in complete mixing with the fuel spray at the injection point and, at the same time, creates a low-pressure zone immediately downstream from the injection point. As the turbulent mixture enters the flame zone, the low-pressure area causes a recycling of hot gases and combustion product back into the mixture. Thus, the mixture is preheated, vaporized, and raised to ignition temperature almost instantly. The flame rotates tangentially into the combustion chamber, and the high intensity allows the combustion chamber to become a reaction chamber. The flame length is short, about 1 to $1\frac{1}{2}$ times the chamber length with high heat release rates upwards of 1,000,000 Btu/hr/ft³ [48].

The burning of nonuniform liquid waste in conventional oil burners can lead to problems. The liquid wastes from the Pittsburgh Plate Glass (PPG) industry plant at Houston is typical of such a waste [49] (see Table 5.5). The outstanding characteristic of these wastes is the lack of uniformity. They are primarily organic, consisting of tars, light hydrocarbons, waxy solids, and heavy viscous oils.

TABLE 5.5. RANGE OF LIQUID WASTE PROPERTIES [49]

Specific gravity	0.886 to 1.053
Viscosity	29 SSU to 3,000 SSU @ 75°F
Flash point, °F	210 to 300
% carbon by weight	7.5 to 10.6
% ash by weight	0.02 to 0.09
% water by weight	0 to 75
% solids by volume	1 to 10
Size of solids	1. One type is granular, up to 1/4 in. dia.
(solids are combustible)	2. Another type is an agglomerated lump measuring up to about 1 in. x 2 in. x 4 in. Solids are soft.
	3. A third variety is a polymer or asphalt-like mass 2 in. thick and measuring 3 in. to 6 in. in the other dimensions. Solids are soft.
Sulfur, %	Negligible
Halogens, %	None
Heating value, Btu/lb.	Estimated maximum 16,000

In an attempt to burn these wastes in any of the six standard types of conventional oil burners, PPG encountered the following problems:

1. High pressure air atomizing burner: A minimum of 80 CFM of free air compressed to 100 psig would have been required to burn the waste at 450 gal/hr. If lower pressures of air were used, more air would have been required. The cost of installation for the additional equipment and piping would have been significant.

2. High pressure steam atomizing burner: From 2,400 to 4,800 lb/hr of steam would be required for conventional atomization.

3. Mechanical atomizing burner: Feed pumps that would deliver oil at a pressure of up to 300 psig would be required. The pumps that were in use at the time were rated at 50 psig maximum.

4. Rotary cup burner: A multiple burner installation would be required to meet the design capacity. This would increase costs and require a more complex control system.

5. Sludge burner type: This type burner tip passes larger solids than the other types, but the maximum orifice size is 1/8 in., and considerable filtering would have been required.

6. Sonic-type burner: Maximum recommended size of solids through this tip is 1/16 in. to 1/8 in.

Pittsburgh Plate Glass therefore developed an incineration system to burn organics. The prototype unit was capable of burning 200 gal/hr of waste. The unit consisted of a 15,000-CFM forced-air fan, and a 6 x 12-ft combustion chamber with multiple air inlets at two opposite corners.

A gas burner mounted on the unit is fired at 3×10^6 Btu/hr to preheat the combustion chamber for smoke-free startup [50]. Combustion air from forced draft blowers enters the refractory and chamber through several ports to provide the desired flame pattern. Sludge is fed into the chamber in such a way as to minimize its being carried by the gas stream. Fuel for combustion consists of the vapors which are evolved from the surface of the sludge exposed to the intense flame and radiation from the walls. The outlet temperature exceeded 2,000°F and suitable decomposition was attained [50].

In the course of the past 10 years, it has become necessary for some industries to convert their boilers from coal to gas to oil and back to coal

again. Consequently, the capability to burn mixed fuels still exists at some levels of industry. In addition, the design of coal-fired boilers capable of firing a wide range of coal is underway. The increase in initial cost is believed to be justified in many cases, for the design also opens the doors to a wide range of liquid gases or other solid fuels.

Since pulverized coal is suspension-fired, as are conventional liquids and gaseous fuels, the furnace is properly proportioned and readily adaptable to this function. Oil or gas is required for the unit to warm up; therefore the required piping, combustion controls, and fuel-firing equipment are already in place. These can be fired to supplement or carry the load with little or no design equipment modification [13].

Well-prepared solid wastes may also be burned in suspension. Up to 20 percent or more of the total heat input may be added through solid waste. Bark, bagasse, and refuse-derived fuel have successfully been fired in suspension-fired, pulverized coal boilers. These wastes can be blown in through ports situated above the burner [13].

For stoker-fired boilers, the burning of liquids and gases is more difficult. Firing equipment, however, can be added above the stoker to protect it from the radiant heat. This addition reduces furnace volume but the disposal of waste in this method might produce suitable tradeoffs [13].

Stokers are ideally suited for the firing of unsized solid fuels. Bark, bagasse, and refuse-derived or containerized tars can be normally fired in a stoker with minimum modification. Wastes can also be allowed to comprise a higher total percentage of the heat input in a stoker boiler than could be permitted in a pulverized coal-fired boiler [13].

Sludges are a class of solids that do not lend themselves to efficient combustion in cell-type furnaces on cast iron grates. Unless the sludge is constantly broken up in a furnace, the waste will form a gas-tight skin that will prevent the penetration of oxygen for combustion. Mechanical means of breaking up the mass of sludge can be accomplished through multiple hearth furnaces, rotary kiln, and fluidized solid reactors.

A multiple hearth furnace consists of a series of circular hearths placed one above the other and enclosed in a refractory-lined shell. A vertical rotating shaft through the center of the furnace carries the arm and rabble

blades that stir the charge and move it in a circular path across each hearth. Waste material is fed to the top hearth and rabbled across it to pass through the drop holes to the hearth below. It passes in this way over and across each hearth to the center of the periphery consecutively until it reaches the bottom and is discharged as ash [50]. The hot products of combustion pass upwards countercurrent to the sludge cake. In the upper hearth, the hot gases evaporate moisture in the waste. Combustion begins in the lower hearth and progresses until all of the combustibles are burned out.

The rotary kiln is occasionally used for sludge and similar waste. The kiln revolves at about 38 rpm and thereby transports and breaks up the solids as they move through the combustion zone [51].

A relatively new device, designed for the incineration of wet ashes and similar wastes is the fluidized bed principle. The principal component is the reactor that is a vertical, cylindrical, refractory-lined chamber. An air stream at approximately 20 oz/sq. in. is injected below and into a sand bed, which serves to fluidize it. A separate pipeline brings air-borne sludge into the fluidized bed which has been preheated. If the waste is autocombustible, the bed is kept at a predetermined temperature. The reaction is a combustion or rapid oxidation of waste sludges [51].

6.0 CURRENT DISPOSAL PRACTICE

Information on current disposal practices and trends was obtained from three sources: Federal, State, and private industry reports and contacts. The main points received from each of these sources are surveyed in this section to indicate the pattern of information developed during this initial phase of study. Section 6.4 then discusses this pattern and its implications for changes in onsite burning of waste by industry to recover energy.

6.1 Federal Sources

Contractor reports for Office of Solid Waste (OSW) in the mid-70's provided an overview of quantities and types of materials generated by various industrial sectors and the treatment and disposal methods then in use [37]. As pointed out in Section 4, five industries have been identified as having appreciable potential for burning organic wastes to recover energy (see Table 4.1). Thus, materials which were formerly landfilled, or otherwise disposed of, might be burned as fuels.

The organic chemicals industry is the largest generator of combustible waste [21]. The prevalent methods of treatment disposal are landfill, incineration, deep well injection, lagooning, and activated carbon adsorption followed by thermal regeneration of the activated carbon. Incineration is widely practiced and in some facilities wastes of sufficiently high caloric value are burned for energy recovery. No estimate was given in the cited report of the quantity of waste burned.

Another study [21] has estimated that some 1.5 million metric tons of combustible waste are available for energy recovery. These burnable materials vary widely in form, ranging from nonviscous liquids to viscous liquids and mixtures of liquids and solids, including tar-like matter which is difficult to transport and tends to plug lines and burners.

Burnable wastes in the plastics industry are estimated at 445,000 tons per year [21]. These are mostly bottom wastes from distillation columns and out-of-specification materials. The latter may contain inorganic pigments, additives such as stabilizers, and fillers. The combustion products may contain unburned hydrocarbons and fly ash with trace metals such as cadmium, nickel, antimony, and lead.

Some refinery waste streams have appreciable potential heat content. If 18.4 MJ/kg (4,400 Kcal/kg or about 8,000 Btu/lb) is the threshold for "stand-alone" energy recovery, without the need for auxiliary fuel, then only the nonleaded product tank bottoms appear to be eligible for energy recovery. These wastes have components--phenols, polycyclic aromatics, and heavy metals--that would be of concern to air quality regulators.

Pharmaceutical industry processes may generate wastes similar to those from organic chemical synthesis, or may generate waste solvents which have been used to extract pharmacologically active agents from a biological matrix and biological wastes also. It is estimated that 65,000 metric tons of wastes usable as fuel can be obtained from pharmaceutical-type plants [21].

In the tire industry, it is estimated that 31,000 metric tons of combustible waste with the potential for energy recovery are generated annually [21].

6.2 State Sources

Published reports of State hazardous waste inventories and disposal practices were used, as well as telephone contacts with State and local environmental protection officials, to develop more details on the burning of hazardous wastes for energy recovery both onsite and offsite with respect to the waste generator. Although the quantitative detail was far from what is needed to accurately assess the magnitude of the various disposal practices and the resulting air quality impacts, the information developed was useful in highlighting the enormous variety of such practices.

Table 6.1 shows the distribution of wastes among onsite treatment methods in New York State [41]. The category "reclaimed for fuel or material value," which constitutes about 26.5 percent of the waste disposal onsite, includes the materials shown in Table 6.2. Among these materials, it appears that the solvent mixtures and nonemulsified waste oils along with some portion of the nonhalogenated solvents would be likely candidates for cofiring for energy recovery. If so, some 90,000 m³ of supplementary fuel at a nominal value of 28,000 MJ/m³ are available to industry each year by burning this waste onsite. How is this being done?

Some plants in New York have applied for permits to burn either waste solvents or oils, or both, as fuels [52]. As an example, a lightweight aggregate plant is using a mixture of oils and solvents as auxiliary fuel for its

TABLE 6.1. SUMMARY OF ONSITE TREATMENT METHODS OF HAZARDOUS WASTES
IN NEW YORK STATE [41]

Type	Approximate quantity in tons	Percent
Distillation	48,508	8.67
Neutralization/precipitation	2,143	0.38
Oxidation/reduction	17	--
Incineration	93,846	16.78
Land disposal	154,168	27.56
Lagooning	65,606	11.73
Other	17,602	3.15
Reclaimed for fuel or material value	148,469	26.54
Storage	<u>29,075</u>	<u>5.20</u>
Total	559,434 Tons	100.00

TABLE 6.2. WASTES RECLAIMED FOR FUEL OR MATERIALS IN NEW YORK STATE [41]

Waste	Quantity	
	Volumetric	Mass
	m ³	Metric tons
Other acid solutions	10,597	0
Cyanide solutions	0.946	0
Inorganic liquid-heavy metal	53	0
Other inorganic solids	0	5,606
Inorganic gases	0	340
Other halogenated solvents	409	0
Nonhalogenated solvents	13,009	0
Mixture of solvents	61,113	0
Halogenated organic liquids	15	0
Other organic liquids	276	0
Heavy metal sludge	31	0
Ink solids and sludges	49	0
Paint solids and sludges	0	236
Scrubber sludge	189	0
Wastewater treatment sludge	0	11.8
Silicon tetrachloride	0	4.5
Dust collector waste	0	53
Nonemulsified waste oil	28,236	0
Emulsified oil	2,521	0
Epoxy resin waste	0	0.9
Lagoon bottoms	9	0
Lagoon tops	7.6	0
Nonhalogenated still bottom	220	0
Nonhalogenated tank residue	0	27
Off-spec chemicals	0	0
Photographic chemical waste	287	0
Spill cleanup	45	0
Textile coating solutions	1,893	0
Rinse water and waste waters	3,785	0
Mixed oils	26.5	0
Other mixed waste	10.3	0

kiln burners. In addition to these admitted users, there are probably a number of firms who are burning such wastes without applying for permit modifications [52]. Although New York air quality officials would rather encourage recycling than burning, there is advocacy for the burning of toxic substances, such as PCB-contaminated oils or solvents and halogenated solvents offsite in mineral product industry kilns under carefully specified and controlled conditions [52].

As specific examples of use [53]:

1. Alpha Cement Company (Jamesville, NY) operates a coal-fired, wet process kiln, 375 feet long, 11 feet in diameter, with a firing rate of 5 tons per hour of 12,500 Btu/lb coal. Particles are controlled by an electrostatic precipitator. Since 1976, this company has been blending-in waste solvents such as ketones, alcohols, acetates, and benzenes which contain colloids (paint sludges). An example, in 1978, some 1,600 m³ (422,000 gallons) of such solvents with a heat content ranging from 27.9 MJ/kg to 41.8 MJ/kg (12,000-18,000 Btu/lb) were burned at a rate of 315 cm³/second (5 gallons/minute)--about 25 percent standard fuel (coal) replacement.

2. Northeast Solite Company (Sangerties, NY) operates two lightweight aggregate kilns--each with a capacity of 16.8 metric tons/hour--using solvents and oil as fuel on a 100-percent replacement basis. The consumption rate is about 2.18 m³/hour for each kiln. Typical fuel composition is 96 percent solvents and 4 percent waste lubricating oil; 35 percent aromatics (benzene, xylene, toluene); 35 percent aliphatics (mineral spirits, petroleum oils, hexane, heptane); 15 percent alcohols (methanol, ethanol, isopropyl); 5 percent ketones (acetones, MEK, MIBK); 5 percent esters (butyl or octyl phthalates); and 5 percent polymeric resins (alkyds, cellulose). When chlorinated solvents are added, they are kept to about 2 percent average because of the corrosion problems they cause in the scrubber and exhaust fan system. Each kiln is equipped with an impingement-type scrubber. Waste cement dust is used to neutralize acids in the scrubbing water to keep pH at 5-6. The temperatures in the kiln thermal expansion zones are at about 1,121°C (2,050°F), and the gas residence time is about one second.

3. Norlite Company (Cohoes, NY) operates a single lightweight aggregate kiln in which the temperature is about 1,177°C (2,150°F), and gas residence

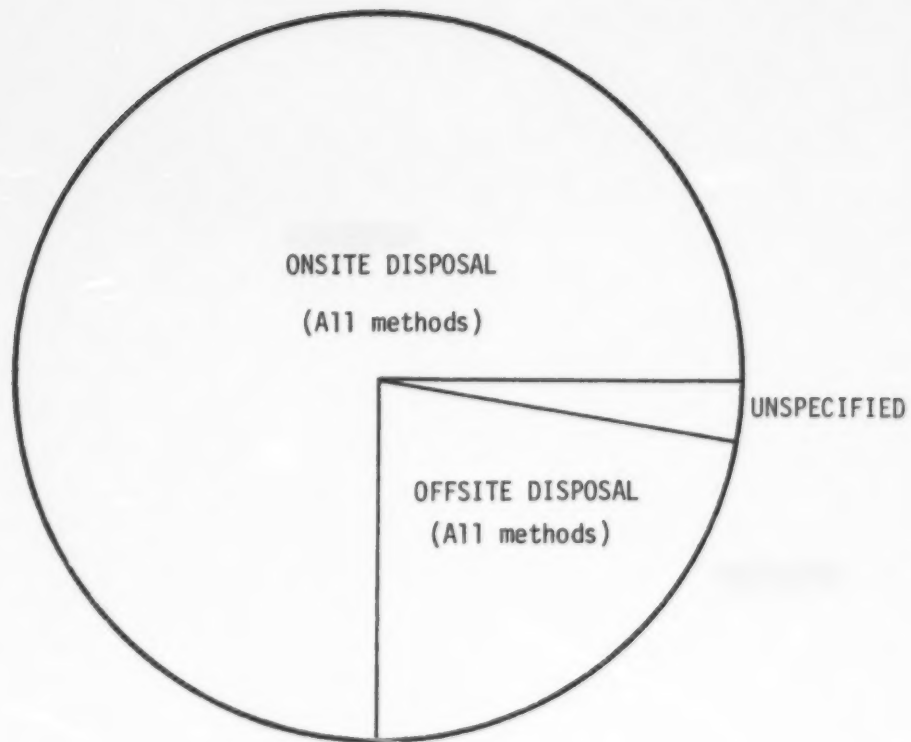
time is about one second. Waste solvents are burned at a rate of about $2.16 \text{ m}^3/\text{hour}$ (570 gallons/hour). These have an average heat content of $22,300 \text{ MJ/m}^3$ (80,000 Btu/gallon). Typically, halogenated solvents are used at about 2 percent composition. Other constituents and their composition ranges are: MEK (20-80 percent); MIBK (0-10 percent); acetone (10-30 percent); toluene (20-80 percent); mineral spirits (5-20 percent); isobutanol (0-5 percent); methanol (0-10 percent); ethanol (0-10 percent); isopropanol (5-15 percent); acetates (5-10 percent); sulfur (0.2 percent); ash (5 percent). Particles are controlled by an impingement scrubber.

The State of Illinois hazardous waste survey, cited previously [43] in Section 4, has yielded data to support estimates that almost 75 percent of these wastes are disposed onsite and 22 percent disposed offsite, as shown in Figure 6.1. Details were shown previously in Table 4.8 of this present report. Of the materials disposed onsite, Illinois environmental protection officials estimate that 33,000 metric tons are burned as fuel. The materials and their quantities are as shown in Table 6.3. Note that the quantities in mass units and those in volume units are additive.

In Illinois, a permit is required if wastes are to be burned as fuel. Application must be accompanied by an analysis of the waste. Usually only sulfur and trace metals content are of concern to the Illinois EPA air quality officials. Only a few companies have applied for a permit. One planned to

TABLE 6.3. TYPES OF WASTE AND QUANTITIES (ANNUAL) BURNED ONSITE AS FUEL BY ILLINOIS INDUSTRIES [43]

Type	Quantity Metric tons	m^3
Oil	0	12,203
Low flash point solvents	1,639	3,497
Chlorinated solvents	0	7.2
Dye and paint sludges	0	1.8
Fats and waxes	0	608
Nonmetal inorganic dusts	3	0
Nonchlorinated organic solids	0	15,261



	<u>Thousands of Tons</u>	<u>% of Total</u>
Disposal Onsite	13,752	74.5
Disposal Offsite	4,052	22.0
Disposal Unspecified	<u>651</u>	3.5
Total	18,455	

Figure 6.1. Projected industrial waste disposal in Illinois statewide [43].

burn solvents, and two were burning fatty acids and oily residues from vegetable oil processing.

In the State of Maryland, although recycling is encouraged, the burning of waste oils and solvents is not discouraged [45]. There have been instances where waste handlers have dumped such materials into open lagoons. Burning as fuel under controlled conditions is viewed by Maryland's environmental protection officials as a much better alternative. The State does want a typical sample analysis along with a sample of the material to be burned. This is checked for PCBs and Pb. If these are present, the blend ratio is restricted to reduce emissions. There are also operating problems. PCBs corrode precipitators and lead fouls boiler heat transfer surfaces. Although there is at least one firm that collects waste solvents and sells mixtures such as MEK and toluene as a fuel (at less than 10 cents/gallon), only one firm has applied to the State for a permit to burn waste solvents. This is a printing firm that burns ethyl alcohol and toluene in a conventional boiler. This is blended at about 10 percent with either No. 2 oil or gas. The State suspects that the burning of oil and solvents, both onsite and offsite, for energy recovery is a common practice and will become even more prevalent; but at present, the State has little solid information on the practice.

In the State of North Carolina, at least two organic chemical firms burn process wastes (DMT sludges) for heat recovery [54]; a pharmaceutical firm burns solvents [55]; and a furniture manufacturer has applied for a permit [56] to burn pretreatment sludge, scrapings and trash from a paint line, and wood scrap with natural gas as the primary fuel in a package boiler. Also, one resin manufacturer uses fumes from its process as its sole fuel [57].

In the State of South Carolina, several examples of industrial burning of wastes for fuel were given [58]. An analysis of the waste must be supplied to the State before a permit is issued. One asphalt plant tried burning phenols, but problems occurred and the practice was stopped by the State. An unspecified firm received permission for a "one-shot" burn of 55,000 gallons of tars from a manufactured gas storage tank. Another unspecified firm buys "all burnable material" for energy recovery. A small secondary aluminum foundry uses waste oil in its smelting. State environmental protection officials suspect that a lot of waste oil, solvent, and other chemicals are being burned in small boilers, but they have no definite information.

In the State of Georgia, there are "two or three" facilities that process waste oil for fuel [59]. Such reprocessed oil and some solvents are used as fuel supplements in pulp mills. This apparently is also common practice in pulp mills in the State of Washington [60]. Blends of up to 20 percent reprocessed lube oil and Bunker C are commonly burned both in pulp mill boilers and in cement kilns [60]. One oil reprocessor [61] estimates that 95 percent of the motor oil reclaimed in the Northwest is burned in boilers, and most of the rest is used on roads.

In the State of Oregon, one firm was reported to be burning shredded rubber tires and wood waste for energy recovery, and two tallow firms were reported to use waste oil for their process heat units [62].

The heavy concentration of petrochemical and refining firms in the State of Texas and the needs for process heat in such operations make this State a prime target for a study to determine the nature and extent of such practices. The Texas Air Control Board (TACB) has no regulations concerning cofiring but uses Federal regulations which require permit applications to appropriate State or local agencies. The guidelines applied by TACB are discussed in Section 9. Through these permits, information is available concerning present practice. For examples [63,64]: Houston Power and Light has applied for permission to burn PCB-contaminated mineral oil in a high efficiency boiler; a coal tar plant is burning waste creosote for heat recovery; ARCO Chemicals, Oxirane, and Shell Oil recover heat from fuels obtained from the pyrolysis of waste streams that were previously landfilled; Diamond Shamrock burns vinyl chloride monomer and ethylene dichloride process wastes in a vapor-heavy liquid incinerator equipped for energy recovery; Dow Chemical is installing incinerators with waste heat boilers to recover energy from burning waste chlorinated and other hydrocarbons; Shell, Tenneco, and Shinpech are incinerating PVC with heat recovery; and Union Carbide cofires waste gases and organic liquids in high efficiency boilers. Even with these copious examples, TACB believes that the tempo of such waste burning will not change much in the future, but that industry will try harder to suppress waste generation or will try to recycle as many materials as possible rather than burning them for energy recovery [64].

The State of Massachusetts, through a manifest system that has been in operation for several years, has compiled an inventory and information on the

flows and disposal methods for hazardous wastes generated in the State. This is discussed in Section 4.2. Currently, it is estimated that much of the waste oil and about one-third of the solvents collected by waste handlers in the State are used for fuel either in the State, or in one of the surrounding States [65]. Much of this material is burned in small boilers supplying heat to greenhouses. One large brick manufacturer was using large amounts of waste oil in its kilns but recently applied for a permit to switch from oil to coal for its operations [65]. Since the State does not require permits for such waste cofiring, there is no definite information on the extent of the practice. However, it is suspected to be widespread now and even more so in the future [66].

6.3 Nongovernmental Sources

A survey of the open literature over the past decade or so did not yield a large amount of information that would provide a definitive picture of current industrial practice. There is enough, however, to indicate that the technology has been steadily developing under the impetus of rising fuel prices and stricter waste disposal regulations.

The American Society of Mechanical Engineers (ASME) has for many years charged a Research Committee on Industrial and Municipal Wastes (RCIMW) with the responsibility of identifying important research problems, sponsoring surveys, research and prototype installations and coordinating seminars, and organizing conferences and similar professional activities to exchange information and stimulate professional interest in the solution of the problems associated with environmentally sound waste reduction. This committee has, among other activities, produced reports on the thermodynamic properties of an enormous variety of materials to aid the design calculations of combustion engineers [67,68], has produced reports on state-of-the-art waste disposal installations [69], and published the proceedings of a conference on the status and research needs of energy recovery from wastes [70]. This committee also coordinated the ASME response to OSW's proposed hazardous waste regulations.

The predominant emphasis of ASME/RCIMW has been on incineration for disposal, but the 1976 conference [70] included a session on waste heat utilization. The applications discussed were focused on specially designed incin-

erators with boilers for heat recovery. No direct utilization in standard boilers by cofiring was discussed except for RDF from municipal wastes.

A paper presented at the 66th meeting of APCA (1973)[37] gave an overview of burning wastes in industrial boilers. The physical properties and heat content of various industrial wastes were discussed, and several methods of burning for heat recovery were described. One furnace design for the steel-making process could burn blast furnace gas 2.9 MJ/m^3 (78 Btu/ft^3), oil, 42.9 MJ/kg ($18,500 \text{ Btu/lb}$), creosote bottoms, 38.3 MJ/kg ($16,500 \text{ Btu/lb}$), and naphthalene, 39.8 MJ/kg ($17,162 \text{ Btu/lb}$).

A subsequent paper by the same author [71] dealt with the design and operating factors for burning wastes in industrial boilers. In particular the author pointed out, "Liquid wastes with reasonably consistent properties, such as solvents or waste oils, can be introduced into a boiler with a conventional oil burner. Only slight burner modifications, depending on the physical properties of the fuel, would be required for proper combustion."

Another combustion engineer has described [14] a specially designed direct-fired unit that uses a waste gas of $3.3\text{-}3.7 \text{ MJ/m}^3$ ($88\text{-}100 \text{ Btu/ft}^3$) to heat a process fluid. In discussing liquid wastes, the same author points out that the economic incentive to recover energy is the escalating cost of conventional fuels. "As a result, plant and process supervisors are looking for any material which has combustion value...." The author provides six examples where liquid wastes have been used to replace conventional fuels in boilers and other heat transfer equipment. These are shown in Table 6.4, taken from Reference 14. These wastes were burned using a vortex burner designed to provide the high turbulence required for effective mixing of the wastes with combustion air. A recent paper [72] has described the use of crude tars from the coking process in a steel plant to routinely replace Bunker C as the backup fuel for conventional boilers generating steam at 400 psi and 600 psi.

The use of package boilers to burn gaseous, liquid, and solid wastes as fuels has been described [73]. The same author has cited the environmental advantages of such combustion over landfilling--assuming, of course, that complete combustion occurs. However, this author also points out that many of the wastes will produce effects that require proper design and maintenance to keep under control. For example:

TABLE 6.4. LIQUID WASTES BURNED FOR ENERGY RECOVERY IN CONVENTIONAL HEATING EQUIPMENT [14]

Waste fuel	Equipment	Firing rate, MJ/hr
Diethylene triamine tar (viscosity similar to No. 6 fuel oil)	Petrochem heater	3,165
Irradiated organic moder- ator from nuclear reactor similar to phenolic tar stillbottoms	Packaged boiler	3,165
Tars, water, misc. organics, ammonium sulfate, ammonium nitrate	Foster-Wheeler Waste Heat Boiler	101,280
Phenolic tars	Steam Superheater	7,385
Toluene-diisocyanate residue (viscosity 3,500 SSU @ 300°F)	Babcock and Wilcox Boilers	84,400
Alpha methyl styrene	Therminol Boiler	7,385

"Some waste fuels will require a greater number of sootblowers, particularly if the fuel has unusual slagging characteristics. The boiler must be modified to allow for any additional sootblowers and any extra wash water drains at the bottom of the boiler, and perhaps some lance ports in the boiler sidewall for hand lancing of deposits in the convection bank. ...A high ash content may cause the buildup of deposits in the boiler and, in the case of ash with high vanadium or sodium content, serious metal corrosion and slagging can also occur. It is possible to utilize fuels with these constituents, but extensive water washing is necessary, as well as frequent outages for manual cleaning to prevent corrosion."

These maintenance procedures will produce solid/liquid waste streams that must be tested with respect to the hazard waste criteria to determine classification and proper disposal.

Solid-waste fuels have been burned in industry for years [74]. Table 6.5, taken from the cited reference, shows the materials that had been fired in boilers designed by the authors' firm as of the date of their article (1974). They demonstrate that the most economical situation is when the solid waste is burned as a supplemental fuel in an existing boiler, with the most versatile design being the spreader stoker. Suspension firing requires that the waste be finely divided to achieve total combustion. These authors also discuss new boiler designs for waste-burning. Considerations attendant to the retrofitting of industrial boilers to accommodate different fuels, including wastes, have also been discussed [75].

A final example of some of the solid wastes that could be expected to be burned in industrial boilers is seen in the test-firing of a variety of solid wastes (and some liquids) from the rubber industry in a small (20,000 lb steam/hour at 150 psig) reciprocating grate stoker which was batch fed. The unit was designed to burn reject linoleum and roofing tar paper from a production plant with a secondary fuel (oil) burner mounted well above the grate. For the test burn, the scraps were either mixed or individually injected in batch fashion. The intermittent batch feed caused sudden overload, resulting in smoking that cleared toward the end of the cycle which created a need for shredding and continuous feeding to reduce emissions. Test efficiency was about 50 percent, although it was suggested that 60 percent efficiency could be attained with continuous feed [76].

TABLE 6.5. IN-PLANT SOLID WASTE FUELS [74]

Waste	HHV (Btu/lb)
Bagasse	3,600 - 5,000*
Furfural residue	5,000 - 6,000*
Bark	4,000 - 5,000*
General wood wastes	4,500 - 8,000*
Coffee grounds	4,900 - 6,500
Nut hulls	7,000 - 8,000
Rice hulls	5,200 - 6,500
Corn cobs	8,000 - 8,300
Rubber wastes	11,000 - 19,700
Leather scrap	12,000 - 19,700
Cork scrap	12,000 - 13,000
Paraffin	16,000
Cellophane plastics	12,000*
Polyvinyl chloride	17,500*
Vinyl scrap	17,500
Sludges	2,000 - 12,000*
Paper wastes	6,000 - 8,000*

*Fired in industrial boilers.

6.4 Trends in Industrial Waste Combustion

There appears little doubt from the previous survey that the burning of waste materials by industry for energy recovery is a viable and growing practice. Large quantities of materials that are landfilled or collected and transported to another location for dumping, with or without containment, will become increasingly diverted to onsite burning. The increasing cost of fuel and the cost of offsite disposal are both "drivers" to this practice.

The combustion technology--design, construction, and operating technique--for waste fuel burning, either as a primary fuel, secondary fuel, or as a more-or-less constant blend, is well established. There is sufficient operating practice base to encourage further exploration and use. Boiler and burner equipment manufacturers are aware of most of the operational problems and methods solving these problems.

7.0 EMISSION DATA AND SOURCE TESTING

Quantitative data are required in order to assess the potential pollutant emissions and the effectiveness of various control methods in reducing such emissions to acceptable levels. These data should relate pollutant species and emission rates to waste-feed composition, combustion conditions, and control methods employed. At present, information on emissions from the combustion of waste materials in industrial boilers is very limited.

There have been many studies of the emissions from various kinds of waste burned in incinerators. The conditions of such combustion are generally quite different from those obtained in industrial boilers, so direct extrapolation is not possible. However, data on the species evolved can be a guide as to some of the pollutants to be expected.

7.1 Data on Hand

Tests were run on the combustion of waste oil and No. 2 distillate blends at Aberdeen Proving Ground early in the 1970's [77]. The waste oil was crankcase oil that was drained from commercial-design vehicles with traces of antifreeze, hydraulic brake fluid, and transmission fluid (in addition to water). A representative analysis is shown in Table 7.1.

A comparison of emissions obtained from burning No. 2 fuel oil and blend of No. 2 with 27 percent waste oil in 3 low-pressure, rotary cup burners is shown in Table 7.2. There was a fivefold increase in particulate matter emissions. The trace metal emissions increased from 44-fold to several hundredfold. The boiler used was rated at 86.3 hp (30,800 lb steam/hr).

A report sponsored by EPA provided data on lead emissions from waste oil blended with coal, No. 2 oil, No. 6 oil, and in one case, burned alone in seven different installations [78]. Table 7.3 taken from this report shows the fraction of lead emitted in the flue gas as a percent of the lead feed rate. Except for the Aberdeen test, these emission fractions can be seen to range from about 25 percent to over 50 percent of the amount in the feed crankcase oil.

Tests on blends of various fuels, designed to assess the problems of burning industrial wastes in conventional boilers [79], have produced some data on NO_2 and particulate emissions.

TABLE 7.1. ANALYSIS FOR NO. 2 DISTILLATE FUEL AND WASTE OIL BURNED
IN ABERDEEN PROVING GROUND TESTS [77]

	Kin. vis. @ 100°F	Gravity °API	Water & sediment	Sulfur % wt.	Total Ash % wt.	Ramsbottom Carbon residue
Waste oil	86.7	24.9	0.1	0.39	1.6	4.36

	Metal content (ppm)			
	Lead	Zinc	Calcium	Magnesium
No. 2 oil	50	30	50	5
Waste oil	6,655	1,331	1,109	1,008
Blend (27% waste)	4,934	518	399	379

TABLE 7.2. COMBUSTION-EMISSION RESULTS FROM TESTS AT
ABERDEEN PROVING GROUND [77]

Test parameter	Results obtained	
	No. 2 fuel oil (No waste product)	No. 2 fuel oil + 27% waste oil

Emissions rate:		
GR/SCF*	0.047	0.262
lb/M Btu	0.031	0.158
lb/hr	0.184	0.938
Visible emissions	0	0
Sulfur content, % wt	0.20	0.25
Trace metal emissions, g/day		
Lead	3.86	172
Calcium	Nil	97
Zinc	1	410
Magnesium	Nil	37

*Corrected to 50 percent excess air, dry basis, 25°C., and 1 atmosphere.

TABLE 7.3 SUMMARY OF DATA ON QUANTITIES OF LEAD EMITTED WITH FLUE GAS AS A PERCENTAGE OF LEAD ENTERING WITH WASTE OIL FUEL [81]

Company	Description of combustion source	Type of virgin fuel	Total fuel feed rate	Percentage of waste oil in feed	Lead content of waste oil	Soot blowing	Lead emitted with flue gas during normal operation as a percentage of lead feed rate	Reference number
Mobil Oil	Steam boiler (18,000 lb steam/hr)	No. 6 fuel oil	147 gal/hr	5 wt %	1%	Yes	50%	42
Shell Oil	Steam boiler (60,000 lb steam/hr)	No. 6 fuel oil	374-476 gal/hr	75 wt %	0.5-1%	No	31%	42
Gulf Oil	Small home oil burner	No. 2 fuel oil	3 gal/hr	25 wt %	1.1%	No	28%	42
Northern States Power Company	Utility boiler (~500,000 lb steam/hr)	Coal	59,360 lb/hr	3.1 wt %	0.65%	Yes	24-61% ^a	61
Kawafian Electric Co.	Utility boiler (~200,000 lb steam/hr)	No. 6 fuel oil	1,900 gal/hr	7.5%	0.45%	Yes	25-29%	62
Aberdeen Proving Ground, Edgewood Arsenal	Steam boiler (5,000 lb steam/hr)	No. 2 fuel oil	~40 gal/hr	30%	0.67%	No	~3%	63
Esso Research and Engineering	Steam boiler (~1,000 lb steam/hr)	None	7.5 gal/hr	100%	0.4-0.6%	No	<50%	57

^aBased on analyses of collected precipitator flyash which contains ash from soot blowing operations.

An incineration system for atactic polypropylene combined with a waste heat boiler for energy recovery has also been described [80]. The system hearth-burns the polymer to pyrolyze the solid. Typically, the system operates at 922°-1,144°K, although a maximum of 1,367°K could be achieved. The pyrolysis gases are mixed with air at about 25 percent excess of stoichiometric requirements. The plastics may produce HCl and P_2O_5 as combustion products. Ash content varies, but could be as high as 10 percent. The temperatures in the pyrolysis zone and entering the heat recovery boiler are kept below the ash fusion point to avoid surface fouling. A typical particle size distribution is shown in Table 7.4.

It has been reported by several authors that, with the burner designs and oil fuels typically used in industrial boilers, the particulate matter emissions depend upon the amount of excess air used. Reed and Wallin [81] found a broad minimum in the range 30-50 percent excess air (10-11 percent CO_2) and pointed out that use of excess air to minimize particle formation was gained at the expense of lower thermal efficiency and higher rates of formation of SO_3 . When burning No. 2 oil in a domestic furnace Wasser et al. [82] found a broad minimum in particle, CO, and hydrocarbon emissions over the range. Skoog and Petersen [83] have reported a similar dependence of particle emissions on excess air. These authors also reported that for the same oil and same boiler, the amount of particulate matter emitted could change by as much as 100 percent for two different burner designs, depending upon the length of the flame.

Although it has been found that under some conditions, the addition of some chemical species, particularly alkali metals, would tend to suppress soot formation [84]. It has also been found that the presence of alkali metal ions will in some cases increase the carbon formation rate [85]. A comprehensive EPA study [86] found that less than 10 percent of 206 commercial fuel additives reduced particle emissions. Thus, it cannot be argued that the presence of metallic ions in waste oil or solvents can be expected to reduce particle emissions.

It has been noted by one author that many gaseous and liquid wastes mask the UV radiation from burner flames "due to moisture and dust" [87].

In a study performed many years ago on coal-, oil-, and gas-fired combustion units, as well as incinerators, Hangebrauck and coworkers found that

TABLE 7.4. TYPICAL PARTICLE SIZE DISTRIBUTION OF ASH
GENERATED IN HEARTH-BURNING OF PLASTIC [80]

<u>Particle Size, microns</u>	<u>% by wt.</u>
850 +	0.86
420-850	4.17
250-420	10.54
150-250	27.82
75-150	39.45
37- 75	8.0
19- 37	4.0
10- 19	2.0
Less than 10	3.2

under certain firing conditions significant amounts of polynuclear hydrocarbons could be generated [88]. It was generally noted that polynuclear emission rates were large when CO and total gaseous hydrocarbon emissions rates were large, indicating incomplete combustion. With benzo(a)pyrene (BaP) as an indicator, there was a consistent increase in polynuclear emissions proceeding from the high efficiency pulverized coal units to the low efficiency hand-stoked home heating units. BaP from oil-fired units was generally much lower than from coal-fired units, but significant amounts of polynuclear materials were generated in an oil-fired unit that used a low-pressure air atomizing burner. Natural gas in premix burners produced relatively low emissions except in one case where the burner adjustment gave an improper high fuel/air ratio.

These results provide a guide to what can be expected from waste-fired combustion sources. When the fuel is well dispersed and mixed with air and combustion temperatures are consistently high, few polycyclic hydrocarbon emissions and high organic content particles can be expected. When mixing is poor, large quantities of these emissions can be expected.

7.2 Data Needed

The brief survey in the preceding section shows that particle emission data and some trace metal emission data exist but far from enough to prepare a proper guidelines document and not nearly enough to form a basis for setting standards. There are little or no data available on hydrocarbon emissions, particularly the higher molecular weight species that are definitely related to, or suspected of such relation to, health risks. It is well known that a sequence of pyrolytic and synthetic reactions can occur in flames to produce polycyclic molecules [89,90], particularly in those cases where the hydrocarbon fuel is not well mixed with air, i.e., in diffusion flames that are typical of liquid combustion.

In the ASME reponse [91] to EPA's proposed regulation on incineration, one example was cited of sampling for hydrocarbon emissions from a 190 M Btu/hr industrial boiler cofiring coal and chemical process wastes. Practically no volatiles (C_1 to C_6 hydrocarbons) were observed, and the gas chromatographable (C_7 to C_{16} hydrocarbons) fraction amounted to only about 5 percent of the organics. It was noted that most of the heavy hydrocarbon emis-

sions condensed in the sampling lines rather than passing through to be deposited on a cartridge of XAD-2 resin for subsequent GC analysis. It should be pointed out, however, that standard EPA Level 1 sampling methods require that the sample lines be as short as possible and heated to 400°F to minimize such condensation.

More importantly, data on particle, organic species, and trace metal emission rates should be correlated with an analysis of the feedstock and combustion conditions. The effect of variation of feedstock composition, boiler loading, and excess air (or equivalently, stack gas O_2) on emissions of particles, SO_2 , NO_x , PNA, and trace metals should be determined to provide guidance on permissible waste/fossil fuel ratios under given conditions. The performance of standard control devices under these same variable conditions should be ascertained to determine if there are any pollutants that are not being adequately controlled and to provide the basis for efforts to improve performance where needed.

Basic to such studies is the research need to work out sampling and analysis methods that will acquire, accurately identify, and quantitate the species of interest. As mentioned previously, there is evidence that higher molecular weight organics are present in the stack. The extent to which such species progress up and out of the stack is at present unknown, as is their transport in, and settlement from, ambient air. However, development of a method for identification and quantification of these species is important, since coal- and oil-fired boilers may also be emitting many of the same compounds.

7.3 Site Selection

From Sections 3 and 4, it can be concluded that there is a large variety of materials used by, or generated in, industry that can be burned for energy recovery. From Sections 5 and 6, it can be concluded that these materials can be and are burned in a large variety of equipment types. In view of these multiplicities of combinations, it is difficult to choose "representative sites for the collection of emission data to guide the development of regulations or to determine whether existing regulations can be adequately applied for air quality protection.

Because of the meager amount of data available on emissions from waste-burning, it appears that the first requirement for source characterization is a Level 1 assessment of several sources which span the spectrum of waste utilization.

Once the sources have been characterized and the nature of the environmental problem more completely analyzed, 30-day (or other appropriate period) continuous emission testing backed up by appropriate reference methods and quality assurance procedures can be used to obtain legally defensible data for standards setting.

The "spectrum of utilization" can be conceptually portrayed by the diagram in Figure 7.1. For a given energy content of waste, the achievement of high combustion efficiency becomes more difficult as the physical state of the waste proceeds from a vapor or a nonviscous liquid up through a semisolid or viscous liquid. Similarly, the combustion type will influence how well the waste is burned, with suspension firing giving the best mixing of fuel and air and hearth burning giving the poorest.

Physical state of the waste is, of course, only one consideration. Another is the chemical composition--including both chemically bound and physically included species. Still another consideration is how well the source is controlled. Large coal-fired units are most likely to have ESP or fabric filtration units to provide efficient particle collection whereas small units may have none at all. A further consideration is how much waste material is being burned or, more properly, what the total pollutant emissions are over a given time period.

A tentative priority listing that would lead to site selection is as follows:

1. Sources burning off-spec resins or plastics or rubber industry wastes in a batch-fed mode.
2. Sources burning semisolid or viscous chemical processing wastes on a continuous or piecewise continuous basis.
3. Sources burning waste lubricating and/or cutting oils on a continuous or piecewise continuous basis.
4. Sources burning waste solvents from metal or semiconductor processing operations on a continuous or piecewise continuous basis.

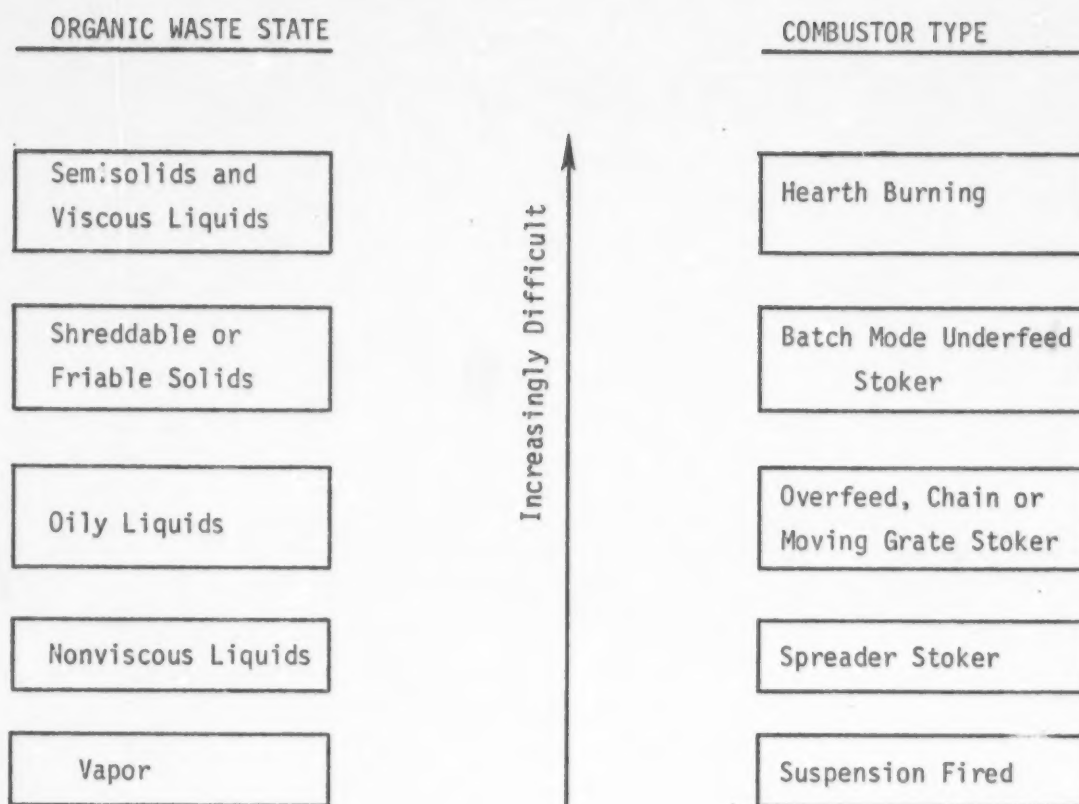


Figure 7.1. Qualitative comparison of organic waste state and combustor type in achieving high combustion efficiency

The presumption made in this listing is that incomplete combustion presents the most severe environmental hazard through polycyclic organics including such species as dioxins and dibenzofurans. Also the burning of products (plastics and rubber goods) that contain a variety of fillers and additives offers more possibility of inorganic emissions than those expected from, say, settled or filtered lube oils or solvents.

7.4 Source Testing Overview

A generalized source diagram is shown in Figure 7.2. Circled letters indicated on the diagram are sampled points. Table 7.5 summarizes these samples. The letter "R" with a subscript appropriate to each stream indicates rate and flowing condition information to be obtained on the particular stream.

The costs shown are rough estimates; additional solid or liquid samples would add about \$2,000 each. The bioassays are by the Ames test and cytotoxicity, but no more thorough animal-based tests. The costs would vary with site, contractor, and perceived degree of difficulty in logistics. Special analyses (e.g., high resolution gas chromatography/mass spectrometry) would also add to overall cost. In view of the anticipated occurrence of incomplete combustion, methods to identify and partially quantify POMs would appear to be essential, as would special care to see that these are recovered from sample lines and probes.

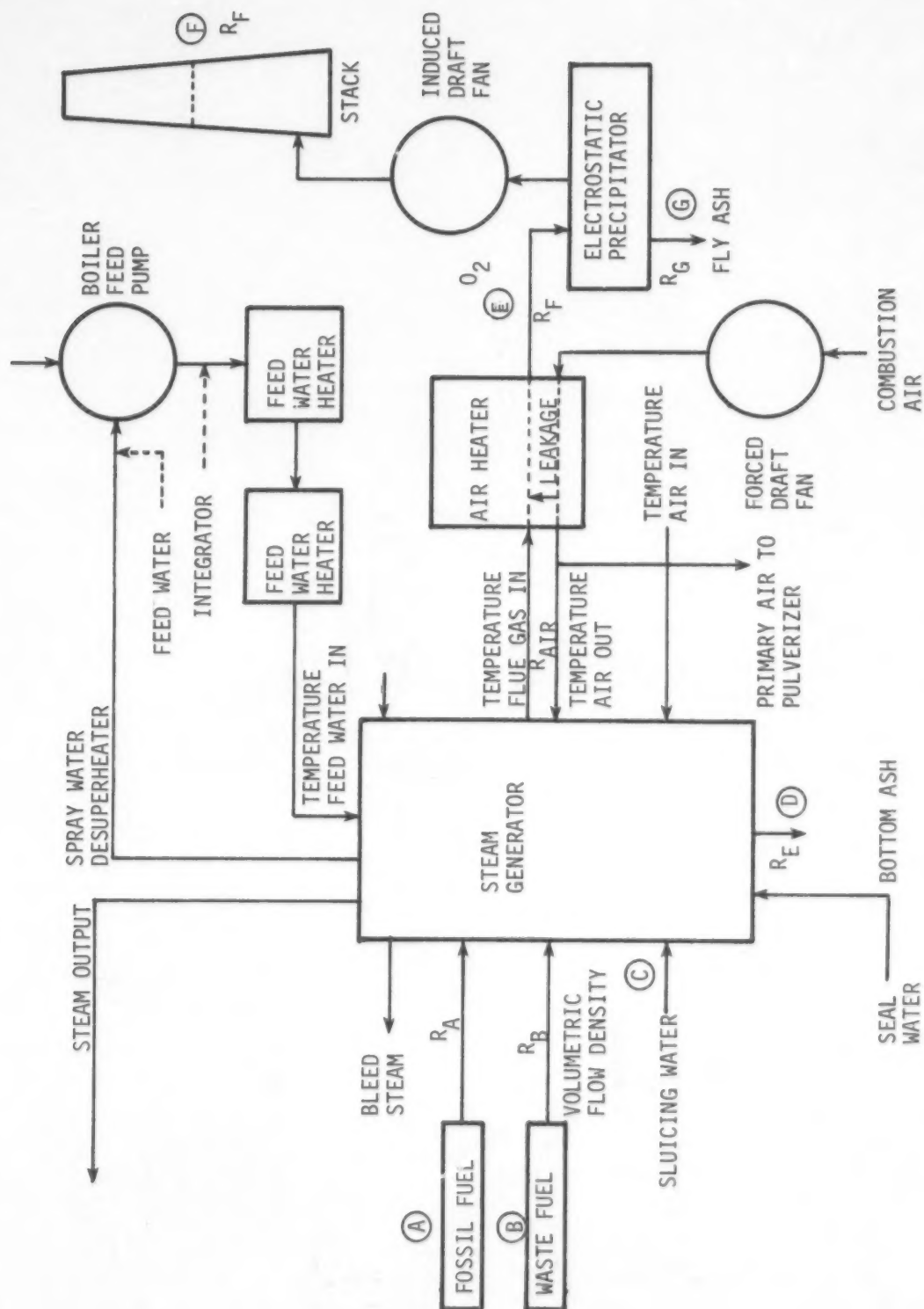


Figure 7.2. Sample points for generalized source screening tests.

TABLE 7.5. SAMPLES FOR LEVEL 1 SOURCE SCREENING FOR WASTE COMBUSTION

Sample	Type	Stream	Estimated cost (1980)	Remark
A	Solid or liquid	Fossil fuel	\$2,000	
B	Solid or liquid	Waste fuel	\$2,000	
C	Liquid	Sluicing water	\$2,000	
D	Slurry	Bottom ash	\$2,000	
E	Gaseous (SASS)	Flue gas prior to cleanup	\$15,000-20,000	Bioassays \$3-5K extra
F	Gaseous (SASS)	Flue gas after cleanup	\$15,000-20,000	Bioassays \$3-5K
G	Solid	Fly Ash	\$2,000	

8.0 CONTROL TECHNOLOGY

When waste materials are burned for energy, the basis for sound environmental control is to assure that:

1. complete combustion occurs;
2. fly ash, particles, pollutant gases, and hazardous vapors emissions to the atmosphere are reduced to a predetermined, safe level;
3. air emission control device residue is properly classified and disposed of; and
4. solid residue (bottom ash) is properly classified and disposed of.

Additional fuel-handling steps prior to combustion must also be considered when planning an overall control strategy. If the waste contains VOC, the processing steps must occur under conditions where the volatiles are not allowed to go into the atmosphere. This has three advantages: air quality is preserved, material with significant heat content is reserved for burning, and safe operation of the plant (prevention of fire or explosion) is maintained. In addition, if the waste is treated prior to combustion to filter out or chemically complex and settle out sludge, the bottom waste from these processes must be adequately handled.

This section will examine these points, review existing control methods, and point out where additional work is needed to provide adequate control technology.

8.1 Combustion Conditions

For complete combustion there must be adequate air, the fuel and air must be thoroughly mixed (turbulence), the exothermic reactions of combustion must provide enough heat to raise the burning mixture to a high enough temperature to destroy every organic constituent, and transport of the the burning mixture through the high temperature region must occur over a sufficient time duration to assure that even the slowest combustion reaction goes to completion.

The general method for calculating both the combustion heat and the adiabatic (theoretical) flame temperature is covered in a number of standard handbooks and texts on combustion [92,93]. Two ASME publications provide thermodynamic data on an enormous variety of materials that may be burned as

waste [68,69]. The heat release rate (in Joule/sec m^3 atm.), the fuel feed rate and heat content, the air feed rate, the increase in gas volume due to the formation of combustion product gases, and the temperature and pressure in the combustion chamber, combined with the load heat-absorption rate and the chamber volume, determine the time-temperature distribution within the firebox [92,94].

Several burner designs for liquid wastes have been described in Section 5.3. These were developed to assure adequate vaporization, mixing, and initial combustion of the particular materials being burned. The waste/ fuel mixture is injected with pressurized air at a sufficient velocity into a geometry that promotes turbulence and circulates some of the high temperature gases back into the incoming stream to raise the temperature of the injected material rapidly toward combustion temperature. The burning mixture is then injected into a flame zone where additional air is supplied to fully develop the combustion.

The hot mixture gains heat from the exothermic reactions and loses heat through:

1. warming the incoming fuel/air mixture,
2. warming auxiliary air,
3. convective heat transfer to the surrounding firebox walls, and
4. radiative heat transfer to the surrounding firebox walls.

The comminution of wastes must be sufficient to promote rapid charring and the distribution of fuel into the combustion zone (e.g., by overfeed from a spreader stoker or crossfeed onto a traveling grate), and combustion air flowing through the char bed and into the resulting volatiles must promote temperatures and mixing sufficient to achieve complete combustion.

As with many environmental control technologies, the proper design to achieve as complete a combustion as possible also provides operational benefits through:

1. better fuel use, and
2. less gum and other residue buildup on the cooler surfaces downstream from the combustion zone.

The needs and procedures for the design and maintenance of proper combustion process controls are well-documented subjects [92,95]. The control system must provide the proper fuel/air feed ratios and insure safe operation.

Included in the safety considerations are flame failure detection, protective interlocks for burner ignition, fan operation, fuel valves, and fuel-air ratio limits. With regard to the latter, the control system must limit the fuel feed to prevent air deficiency, must phase down fuel feed ahead of air feed with a decrease in load, and must phase air feed ahead of fuel feed with an increase in load.

If the waste fuel is not blended in a constant ratio to the regular fossil fuel or if the average heat content of the waste fuel varies significantly, the fuel/air ratio required for proper combustion will also vary. This can be taken into account by using an oxygen analyzer (of appropriate response time) to set the feed ratio [96].

The use of ultraviolet (UV) flame detectors is standard practice on industrial boilers. It has been found, however, that the addition of various wastes as fuels can create a problem of masking the UV detector. This can be due to moisture, dust, or even the flame characteristic. One alternate flame sensor approach to avoid this problem uses the characteristic modulation, at frequencies ranging from below 100 Hz to as high as 600 Hz in various parts of the flame, of the visible and infrared spectral emission components [97].

Any guidelines document to promote the environmentally safe use of waste materials as fuels must also include a discussion of, and recommended design practices for, state-of-the-art combustion controls and interlocks. As with other facets of good environmental design practice, there is also a benefit in this case. A well-designed and well-maintained combustion control and safety interlock system can save fuel, unscheduled shut-downs, and even insurance premiums in those cases where such premiums depend upon a demonstrated history of safe operation.

8.2 Solid Wastes

Section 261.4(b)(4) of the hazardous waste regulations [2] declares that the following are not hazardous wastes (by definition):

"Fly ash waste, bottom ash waste, slag waste, and flue gas emission control waste generated primarily from the combustion of coal or other fossil fuels."

The meaning of the word "primarily" must be determined in order to specify the limits of the feed ratios of waste/fossil fuel under which the exclusion applies.

These same wastes derived from the combustion of wood as the primary fuel could conceivably be hazardous if they do not pass the EPA toxicity test. Unless the exclusion is broadened, the solid wastes from the combustion of wood, or wood and shredded tires, etc., could conceivably require handling and disposal as a hazardous waste.

8.3 Air Emission Controls

It is doubtful that the combustion of waste oils and solvents under properly controlled conditions will constitute any more of a hazard than the burning of coal or heavy oil. Crankcase oil, cutting oils, and many solvents are apt to contain appreciable quantities of metals, but much of this detritus can be treated and settled or filtered out prior to combustion. This not only has environmental advantages, but also it has practical operational advantages. Metal particles, compounds, and sludges can plug lines and orifices and foul heat transfer surfaces. An effective regulatory strategy should include a guidelines document that provides a thorough discussion of the needs for and practical methods for waste pretreatment before burning. Such pretreatment, along with state-of-the-art particle controls, would probably provide effective regulation where wastes are cofired with coal or wood. When cofired with oil, however, there may be more of a problem in achieving adequate stack gas cleanup.

That emissions controls may be necessary can be illustrated by considering the combustion of waste crankcase oil mixed with conventional fuel. It is instructive to take data from Table 7.3 for four cases:

1. Mobil Oil steam boiler (18,000 lb/steam/hr) burning 147 gal/hr of No. 6 fuel oil mixed with 5 weight percent crankcase oil, containing 1 weight of lead, and emitting 50 percent of the lead in the feedstock. This is equivalent to a lead emission rate of $Q = 0.035$ g/s.
2. Shell Oil steam boiler (60,000 lb steam/hr) burning an average of 425 gal/hr of No. 6 fuel oil mixed with 75 weight percent crankcase oil, containing an average of 0.75 weight percent lead, and emitting 31 percent of the lead in the feedstock. This is equivalent to a lead emission rate of $Q = 0.7$ g/s.
3. Hawaiian Electric Company utility boiler (200,000 lb steam/hr) burning 1,900 gal/hr of No. 6 fuel oil mixed with 7.5 weight percent crankcase

oil, containing 0.45 weight percent lead, and emitting 29 percent of the lead in the feedstock. This is equivalent to a lead emission rate of $Q = 0.18 \text{ g/s}$.

4. Northern States Power Company utility boiler (500,000 lb steam/hr) burning 59,360 lb/hr coal mixed with 3.1 weight percent crankcase oil, containing 0.65 weight percent lead, and emitting 25 percent of the lead in the feedstock. This is equivalent to a lead emission rate of $Q = 0.38 \text{ g/s}$.

The first two cases will be assumed to have a stack height of 30 meters (98 feet) and the latter two, a stack height of 70 meters (230 feet).

A simple dispersion model (Turner, Public Health Service Publication No. 999-AP-26, 1969) can be used to estimate ambient air concentration of lead at ground level assuming no settling (i.e., perfect ground plane reflection). In order to bracket the problem, three different meteorological conditions will be used:

WORST CASE: Air velocity 0.5 m/s, stable plume under a stable layer with base 100 meters above the ground plane.

MODERATE CASE: Air velocity 3.5 m/s, neutrally stable plume (typical of overcast conditions) under a stable layer with base 300 meters above the ground plume.

BEST CASE: Air velocity 2.5 m/s, unstable plume with no stable layer above.

These meteorological conditions affect plume dispersion to give the estimated lead concentration values at ground level shown in Tables 8.1, 8.2, and 8.3.

The current primary and secondary national ambient air quality standard (NAAQS) values for lead are $1.5 \mu\text{g}/\text{m}^3$. In the case of a source with a short stack (30 m) firing a large quantity of lead contaminated waste oil, the NAAQS is greatly exceeded well out past 10 km from the source under Worst Case meteorological conditions, and generally exceeded for the other three firing cases shown. Even a 90-percent reduction of particles (assuming equal reduction of the lead emissions) would still leave a problem when large quantities of lead contaminated waste are burned.

Aside from the simplicity of the model, there are several problems with such a naive approach. The lead will probably be emitted in particulate matter form rather than a vapor. The distribution of particle size will depend upon many factors peculiar to each source and condition of burning. Settling of larger particles could aggravate deposition near the source and

attenuate the plume lead content downwind. The respirable fraction of lead-containing particles at ground level is unknown. These are some of the factors that need to be examined in establishing a control strategy to preserve air quality.

Restriction of the lead content of the feedstock is one control method that can be used along with emission controls, where necessary and shown to be practicable, to insure that lead emissions will not pose an air quality problem.

At present not enough information is known to estimate emissions of POM material with the same model. Achievement of high temperatures and reasonable residence times can be effective in keeping emission rates to low values. Whether these are low enough in view of the potential health hazards must be determined by further research.

TABLE 8.1. GROUND LEVEL CONCENTRATION OF LEAD IN AMBIENT AIR ($\mu\text{g}/\text{m}^3$) FOR WORST CASE METEOROLOGICAL CONDITIONS AT VARIOUS DOWNWIND DISTANCES, x

Stack height, 30 m			Stack height, 70 m		
x (km)	Q = 0.035 g/s	Q = 0.7 g/s	x (km)	Q = 0.18 g/s	Q = 0.38 g/s
0.5	0.22	4.5	0.5	1×10^{-12}	2.3×10^{-12}
1.0	4.6	92.4	1.0	8.6×10^{-4}	1.8×10^{-3}
1.7	6.4	128.8	2.0	0.41	0.87
5.0	3.0	60.2	5.0	2.8	5.9
10.0	1.4	28.0	7.5	3.1	6.6
			10.0	1.5	3.1

TABLE 8.2. GROUND LEVEL CONCENTRATION OF LEAD IN AMBIENT AIR ($\mu\text{g}/\text{m}^3$)
FOR MODERATE CASE METEOROLOGICAL CONDITIONS AT VARIOUS DOWNWIND DISTANCES, x

Stack height, 30 m			Stack height, 70 m		
x (km)	Q = 0.035 g/s	Q = 0.7 g/s	x (km)	Q = 0.18 g/s	Q = 0.38 g/s
0.5	1.2	24.8	0.5	0.02	0.03
1.0	0.95	19.0	1.0	0.67	1.4
5.0	0.12	2.3	1.7	0.98	2.1
10.0	0.04	0.8	5.0	0.46	0.98
			10.0	0.20	0.41

TABLE 8.3. GROUND LEVEL CONCENTRATION OF LEAD IN AMBIENT AIR ($\mu\text{g}/\text{m}^3$)
FOR BEST CASE METEOROLOGICAL CONDITIONS AT VARIOUS DOWNWIND DISTANCES, x

Stack height, 30 m			Stack height, 70 m		
x (km)	Q = 0.035 g/s	Q = 0.7 g/s	x (km)	Q = 0.18 g/s	Q = 0.38 g/s
0.5	0.39	7.8	0.5	1.66	3.5
1.0	0.05	0.92	1.0	0.24	0.50
5.0	0.004	0.08	5.0	0.02	0.04
10.0	0.0001	0.003	10.0	0.0007	0.001

9.0 CURRENT REGULATORY APPROACHES

In this section, existing Federal and State regulations are surveyed, regulatory policies are discussed, and possible trends are projected. Throughout, one important question is kept in mind: Are present and projected Federal and/or State regulations sufficient to protect air quality if appreciable quantities of wastes are burned in industrial heating equipment? If the answer to this question is "No" or "Maybe", the next logical question is: What approaches can OAQPS consider in order to provide such protection under existing mandates?

9.1 Regulation by the Office of Solid Waste

On May 19, 1980, OSW published its phase one interim final regulations for a hazardous waste management system [2]. As shown in Figure 1.1 and discussed in Section 1, the current definition of solid wastes specifically excludes material "burned as a fuel for the purpose of recovering usable energy." In commenting on energy recovery, OSW states [98]:

"The Agency has decided that the burning of hazardous waste for energy recovery will not now be covered under the hazardous waste provisions of RCRA. (However, storage or transportation of listed hazardous waste prior to energy recovery is covered by these regulations.)

"Accordingly, if waste oils and solvents are burned as a fuel in a boiler primarily to produce steam or usable energy, this action is not now covered by these regulations."

Whereas the regulation on incineration [99] requires the achievement of steady-state combustion, using auxiliary fuel before wastes are introduced, OSW comments in another part [100]:

"For example, air emissions generated by the burning of waste oil for energy recovery can probably be effectively controlled without requiring boilers to meet hazardous waste incinerator requirements."

The implication appears to be that air quality regulations should govern the use of wastes as fuel.

This implication, if true, apparently contradicts comments made in another place [101]:

"The procedures of the Clean Air Act would be a less efficient way to control a large number of hazardous air pollutants than RCRA, under which design, operation, or performance criteria (such

as incinerator destruction efficiencies) can be set more easily for many pollutants emitted by the facilities. Therefore the Agency has chosen RCRA as the primary vehicle for controlling air emissions from hazardous waste facilities."

In view of this contention and the previous statement, the burning of wastes for energy recovery appears to be an area in which careful coordination between OSW and OAQPS will be required.

OSW has specifically listed a number of solvents as "hazardous waste from nonspecific sources" [102]. These are shown in Table 9.1. Under 40 CFR, Part 262 of the new regulations [103], a generator who treats, stores, or disposes of these materials on site must obtain an EPA identification number and submit an annual report, unless the total amount generated is less than 1 metric ton (1000 kg) per month [104]. A generator who wants to have these substances transported for disposal elsewhere must have first obtained an EPA identification number that is used on a manifest to identify the generator, type of material, and quantity.

The net result of the regulations as currently written is to enable tracking of a portion of the materials that are likely to be burned for energy (i.e., those listed in Table 9.1), but to specify nothing about the conditions under which these materials will be burned.

OSW is presently studying the problem of waste oil disposal. A contractor study of the burning of waste oil in industrial boilers has been conducted [105]. This was not a field study. It uses existing emission data and modeling to consider the potential emissions (primarily Pb) for various feed ratios and rates under steady-state conditions. This study will be one of the inputs used to formulate interim final regulations. Spent solvents are also under study but are behind the waste oil effort. Residues from the production of organic chemicals will be addressed subsequently.

9.2 Regulation by the Office of Air Quality Planning and Standards

The general process used by OAQPS to determine which regulatory approach will be used for a particular air quality problem is shown in Figure 9.1. The characteristics of the regulatory options available are summarized in Table 9.2. As can be seen, all three regulatory approaches require considerable time and effort on the part of OAQPS to implement.

Currently, the substances for which NAAQS values have been established are as shown in Table 9.3. The NESHAP regulated substances are as shown in

TABLE 9.1. SOLVENTS LISTED AS OF MAY 19, 1980, AS HAZARDOUS WASTE

EPA hazardous waste number	Materials	Hazard
F003	Spent nonhalogenated solvents: xylene, acetone, ethyl acetate, ethylbenzene, ethyl ether, n-butyl alcohol, cyclohexanone, and still bottoms from recovery of these.	Ignitable
F004	Spent nonhalogenated solvents: cresols and cresylic acid, nitrobenzene, and still bottoms from recovery of these.	Toxic
F005	Spent nonhalogenated solvents: methanol, toluene, methyl ethyl ketone, methyl isobutyl ketone, carbon disulphide, isobutanol, pyridine, and still bottoms from recovery of these.	Toxic and Ignitable

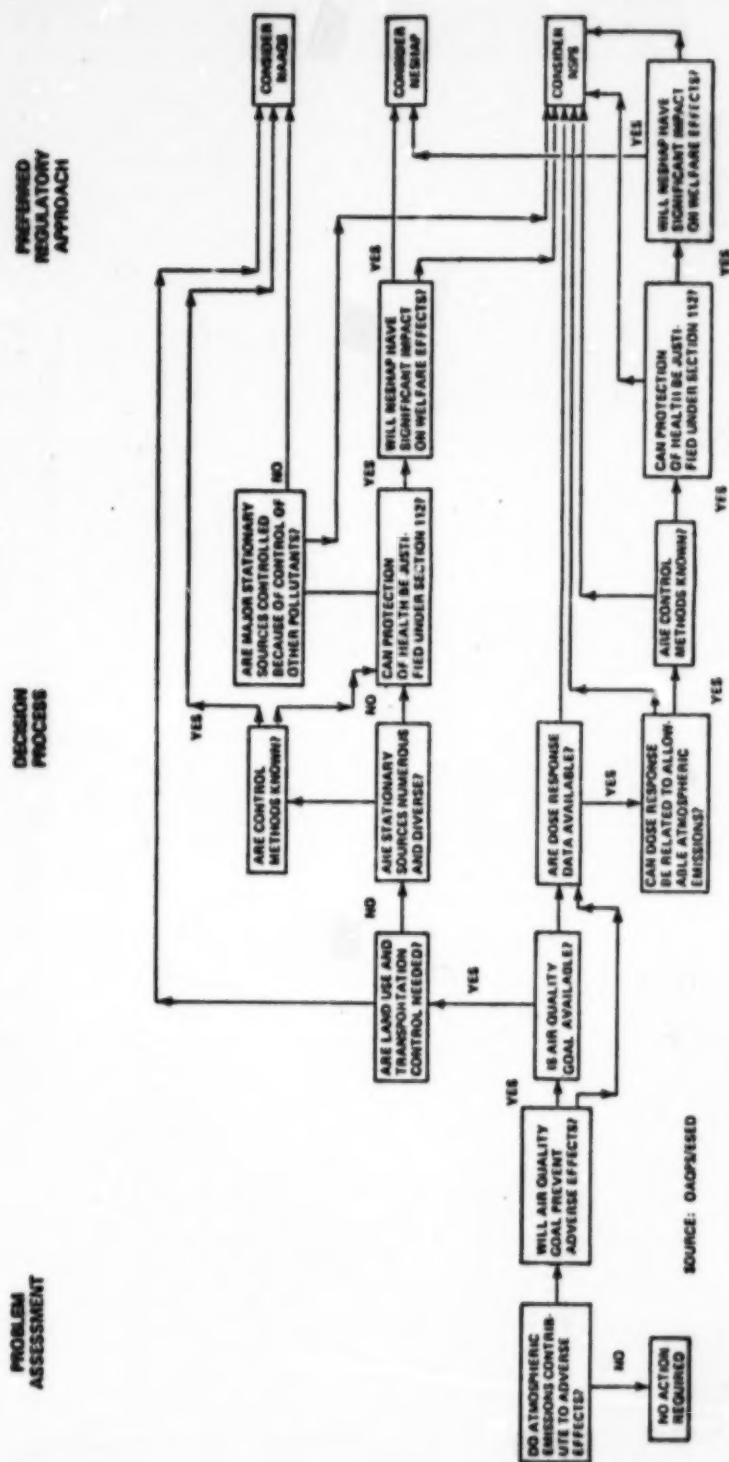


Figure 9.1 Preferred standards path analysis flow chart for air quality programs.

TABLE 9.2 PRINCIPAL AIR POLLUTION REGULATORY OPTIONS

PRINCIPAL REGULATORY STRATEGY	National Ambient Air Quality Standard	New Source Performance Standard	National Emissions Standard for Hazardous Air Pollutants
CLEAN AIR ACT SECTIONS INVOLVED	108, 109, 110	111(b), (d)	112
KEY FACTORS	Pollutant-oriented. Most difficult to write; requires control of all emission sources; acts via State Implementation Plans.	Source-oriented. Specific to industry.	Pollutant-oriented. Health effect involves mortality, serious, irreversible, or incapacitating reversible human illness.
LEAD ORGANIZATION FOR IMPLEMENTATION	States	EPA	EPA
INFORMATION REQUIREMENTS	Health and welfare information; control technologies and costs; effect of emission reductions on air quality.	Administrative judgment of contribution to air pollution; information of effectiveness and costs of control techniques.	Knowledge or emission level providing ample margin of public safety
TIME REQUIRED TO DEVELOP REGULATION	2-6 years or more; additional time is required to develop and implement State Implementation Plans.	Typically 3 years.	Typically 2 years (see Note 2).

Notes: 1. If pollutant is neither a criteria pollutant under Section 108-110 nor a hazardous pollutant under Section 112, States must apply similar control to existing sources of the same industrial type based on best available control technology.
 2. Regulatory process is usually expedited due to public pressure to eliminate health hazards.

TABLE 9.3 NATIONAL AMBIENT AIR QUALITY STANDARDS

Pollutant	Averaging time	Primary standards	Secondary standards
Particulate matter*	Annual (geometric mean)	75 $\mu\text{g}/\text{m}^3$ 260 $\mu\text{g}/\text{m}^3$	60 $\mu\text{g}/\text{m}^3$ 150 $\mu\text{g}/\text{m}^3$
	24-hour	260 $\mu\text{g}/\text{m}^3$	150 $\mu\text{g}/\text{m}^3$
Sulfur dioxide	Annual (arithmetic mean)	80 $\mu\text{g}/\text{m}^3$ (0.03 ppm)	---
	24-hour	365 $\mu\text{g}/\text{m}^3$ (0.14 ppm)	---
	3-hour	---	1300 $\mu\text{g}/\text{m}^3$ (0.5 ppm)
Carbon monoxide	8-hour	10 $\mu\text{g}/\text{m}^3$ (9 ppm)	Same as primary
	1-hour	40 $\mu\text{g}/\text{m}^3$ (35 ppm)	
Photochemical Oxidants†	1-hour	160 $\mu\text{g}/\text{m}^3$ (0.08 ppm)	Same as primary
Hydrocarbons (nonmethane)†	3-hour (6 to 9 AM)	160 $\mu\text{g}/\text{m}^3$ (0.24 ppm)	Same as primary
Nitrogen dioxide§	Annual (arithmetic mean)	100 $\mu\text{g}/\text{m}^3$ (0.05 ppm)	Same as primary
Lead	Calendar quarter	1.5 $\mu\text{g}/\text{m}^3$	Same as primary

*The secondary annual standard (60 $\mu\text{g}/\text{m}^3$) is a guide to be used in assessing implementation plans to achieve the 24-hour secondary standard.

†Expressed as ozone by the Federal Reference Method. Proposed change to ozone published June 1978. Proposed new primary standard 0.1 ppm.

†This NAAQS is for use as a guide in revising implementation plans to achieve oxidant standards.

§This standard is currently under review by the EPA Administrator to determine whether an NAAQS for NO_2 based on a 3-hour average would be more appropriate for public health protection. Discussion of this was scheduled for publication in the Federal Register in January 1979.

Table 9.4. In addition to the latter, the countdown to NESHAP's regulation is well along for benzene, arsenic, coke oven emissions, and airborne carcinogens.

9.3 Regulation by the States

At present most States have filed State Implementation Plans (SIPs) for implementation and enforcement of regulations to protect and enhance air quality. None of these deal specifically with the problem at hand. There is a carryover of the LAPCD "Rule 66" that is still in the plans for a few districts in California and for the Boston Intrastate area in Massachusetts. This limits organic emissions for certain solvents exposed to flame and calls for an 85 percent or better reduction [106].

The State of New York requires a permit to construct and a certificate to operate for sources emitting exhaust into ambient air. The materials to be emitted are classified with respect to their potential for adverse health effects and/or environmental degradation. Then a predetermined percentage reduction is imposed based upon the uncontrolled emission rate for the particular pollutants involved [107]. New York's Department of Environmental Conservation is currently considering a change in regulations to specify that anyone who burns other than fossil fuels must first get a permit, for which an environmental impact analysis would be made [108].

TABLE 9.4. NATIONAL EMISSION STANDARDS FOR HAZARDOUS AIR POLLUTANTS (NESHAP)

Pollutant	Regulation
Abestos	40 CFR 61, Subpart B
Beryllium	40 CFR 61, Subpart C
Mercury	40 CFR 61, Subpart E
Vinyl Chloride	40 CFR 61, Subpart F

The NESHAP standards to date have generally been applied to specific industries rather than across the board to all emitters of the specified substances.

The State of Massachusetts currently does not require a permit to burn waste organics such as oils and solvents, except for mineral oils containing less than 50 ppm PCBs. In the case of these, a recent policy statement formulated by the Division of Air Quality Control calls for, among other things [109]:

1. Department authorization must be obtained prior to the burning of this material, and it must be renewed annually. The Department reserves the right to require applicants to provide detailed boiler information including, but not limited to, combustion temperature and residence time.
2. Analysis of each "lot" of fuel by methods approved by the Department must be made and submitted to the Department prior to its use.
3. The boiler input capacity shall be rated equal to, or greater than, 20 million Btu/hr.
4. Carbon monoxide concentration in the flue gas shall not exceed 0 percent.
5. Excess oxygen shall be equal to, or greater than, 3 percent.
6. These procedures are in addition to the operating procedures specified by the boiler manufacturer.
7. Mineral oil shall be burned primarily during high fire conditions.

A process weight table is used to specify allowable emission rates of particles [110]. With respect to fuels, the regulations deal with fossil fuels except for 301 CMR 7.05 (5) which deals with fuel additives. These are defined as "any substance which is not a natural component of the fuel to which it may be added or in conjunction with which it may be used." [111]. This part of the regulations calls for specific written approval by the Department of Environmental Quality Engineering (DEQE) prior to use. Apparently this section is not being construed broadly enough to include cofiring of wastes. The State Hazardous Waste Division does permit waste haulers and keeps track of materials, quantities, where generated, and where delivered.

The State of Maryland has a specific regulation dealing with waste oils and other combustible fluids, namely [112]:

- "A. A person may not burn, sell, or make available for use as fuel in any installation any waste oil, including but not limited to used petroleum products, crank case drainings, cutting oils, vegetable oils, or combustible fluids salvaged from any

automotive or industrial use, without obtaining prior approval of the Department.

- B. Any person desiring to use waste oil as a fuel in any installation before use, shall submit to the Department any information and analysis the Department may require.
- C. After consideration of the information submitted by a prospective user of waste oil, the Department shall enter an order approving or disapproving the use of the fuel or approving its use with such conditions as the Department finds necessary"

Maryland has been concerned with the burning of PCB-contaminated oil. Their Air Quality people want to make sure that this is burned under carefully controlled conditions. The State has a big problem with liquid organic waste disposal and would not mind if much of it is burned, as long as it is done in an environmentally sound manner.

Except for those sources burning less than 2.93×10^7 watts (100M Btu/hr) of No. 2 fuel oil or less than 7.3×10^7 watts (250 Btu/hr) of natural gas, the State of North Carolina requires a permit which includes a description of the fuel to be burned. This also covers fuel changes such as the burning of wastes.

The State of South Carolina also requires such notification along with a sample of the fuel to be burned, which must be submitted to the State for analysis. This analysis includes: Btu content, sulfur, ash, halogens, Pb, Hg, Cr, V, Cu, Co, Ni, T, Sb, cyanide, and nitrogen.

The State of Texas requires a permit application for cofiring to be submitted to the appropriate State or local air protection agency [113]. Guidelines for evaluating these applications are:

- 1. Stack parameters are required so that TACB can model for hourly and 8-hour predicted maximum ground level concentrations (mgk) for identifiable pollutants.
- 2. For nontoxic substances, the 1-hour and 8-hour mgk may not exceed TLV/30 for the particular substances. For toxic substances the limit is TLV/100. The disposal of carcinogens by cofiring is prohibited.
- 3. Stack sampling is often required.

Permit data, including stack tests where performed, are on file.

Ohio has no specific regulations on cofiring. Standard combustion regulations are used. This has led to enforcement problems. As an example, the

State is presently in litigation with a firm that has been cofiring wastes on a No. 2 fuel oil permit.

The State of Illinois has no regulation that specifically applies to cofiring. The practice is not officially encouraged (in contrast with recycling). The only known permit application has come from a chemical plant that wants to burn solvents in a boiler. This is still under consideration. The State EPA does recognize that tighter land fill controls will force cofiring for energy recovery into a possibly viable option and does plan to move into this area of regulation.

The State of Oregon has no specific regulations for cofiring. Standard air quality permit procedures are followed with variances issued to those applicants requesting cofiring. To date the State has encouraged the cofiring of RDF with other fuels, and will probably do so with other materials if the practice can be shown not to degrade air quality. Wherever feasible recycling is encouraged. The Oregon Department of Air Quality is closely following a one-year trial in which Georgia Pacific is cofiring shredded automobile tires and wood waste at a paper mill in Toledo, Oregon, in a 7.3×10^7 watt (250 Btu/hr) stoker-fired boiler. The variance provides that the tires provide no more than 10 percent of the total heat input, 40 percent opacity cannot be exceeded for any period greater than three minutes and particle emissions cannot exceed 2gr/scf.

9.4 Assessment of Regulatory Status

Perhaps NESHAPs on airborne carcinogens could eventually be used to regulate emissions from the combustion of some organic substances in industrial boilers. From the NAAQS arsenal, perhaps Pb emission control could be considered as a vehicle to regulate waste automotive oil combustion.

Where waste organics are to be burned in new sources, it is possible that the NSPS for industrial boilers can be modified to establish emission limitations on particles, hydrocarbons (perhaps POM), and trace metals that will insure adequate control. Then section 111(d) of the Clean Air Act can be invoked to establish similar controls on existing sources. The major burdens of such a procedure will be:

1. Establishing the species and quantities of pollutants that might be emitted by uncontrolled sources,

2. Establishing the prima facie case that some of these species (if not all) can endanger health and environmental quality,
3. Establishing that effective control measures exist and can be applied reasonably.

In this connection, the definition of a "new source" [114] includes a modification by physical change, or change in method of operation of a stationary source which increases the amount of any air pollutant emitted by such source, or which results in the emission of any air pollutant not previously emitted. Thus, the change from fossil fuel to cofiring, if it can be shown to cause the emission of additional pollutants, might be construed as qualifying the source as "new."

The current thrust of the NSPS being prepared for industrial boilers is to specify the best system of continuous emission reduction (taking into account cost and cross-media effects) for the criteria pollutants. The rationale is that such control will also be effective for most of the non-criteria pollutants as well [115].

The current regulatory status concerning waste combustion in boilers could be fairly summarized as a state of limbo. Heretofore, the combustion of waste materials as fired represented only a very small fraction of the total material burned, both as fuel and by incineration. As such, the problem was minute. Now that there is a strong trend toward much more such combustion, there is a question as to whether current regulations are sufficient to provide adequate control to assure air quality.

This question cannot be answered until much more is known (i.e., quantitative data are obtained) about the waste fuel composition, the conditions of combustion, the species emitted, and their dependence on feed and firing conditions. In addition, there is much to be learned about the operating practices and maintenance required to assure essentially complete combustion if guidelines are to be prepared.

Many States now have regulations that require a fuel analysis and notification to the State agency before a permit holder is allowed to burn a significantly different fuel. There is abundant evidence that this requirement is not, and perhaps cannot be, enforced.

In cases where notification and a fuel analysis is provided, the States have generally done some dispersion modeling, looking at sulfur and perhaps

lead. PCB-contaminated oil is a special case. There has been sufficient publicity, public arousal, and EPA and State guidelines for compliance to be effected.

The ability of combustion sources to produce potential carcinogens under certain conditions has been long known, but the translation from laboratory studies to the assessment of combustion conditions in commercial burners has been slow. Laboratory-operating variables are more easily controlled than large-scale boiler-operating variables. Laboratory sampling and analysis can be carefully worked out. Field studies are conducted in and around busy plant personnel and equipment pieces. Laboratory samples can be analyzed almost in situ if necessary. Field samples are collected, transported, stored, and then--eventually--processed. There is ample opportunity for transformation, "plating out" on container walls, and transition from physical adsorption to chemical adsorption to occur.

In spite of these difficulties it is incumbent upon EPA to assure that their field measurement methods are indeed developing representative data. The presence of pollutant species must be proved and quantitated, then compared to health risk assessment data in order to provide the basis for regulation. A null result or the emission of quantities demonstrably below minimum reasonable health risk levels cannot justify regulation, no matter how suspicious the result.

In the interim, it appears that enforcement of existing particulate emission and opacity regulations are the first line of air quality defense. Collection of particles, especially at low enough temperatures to effect adsorption of higher molecular weight organics, can serve to greatly reduce the emission of metals and polynuclear aromatic compounds.

REFERENCES

1. Resource Conservation and Recovery Act of 1976. Public Law 94-580, 90 Stat. 2795, October 21, 1976, as amended by Public Law 95-609, November 8, 1978.
2. Environmental Protection Agency. Hazardous Waste Management System. Federal Register 45(98), 33068-33285, May 19, 1980.
3. *ibid.*, p. 33119.
4. *ibid.*, p. 33121-33124.
5. *ibid.*, p. 33119.
6. *ibid.*, p. 33119.
7. Reference 2, p. 33094.
8. Reference 2, p. 33095.
9. Phillip W. Powers. How to Dispose of Toxic Substances and Industrial Wastes. Noyes Data Corporation, Park Ridge, NJ, 1976.
10. Yen-Hsiung Kiang. Total Hazardous Waste Disposal Through Combustion. The Combustion Institute--1977 Spring meeting, "Combustion Technology for Pollution Control", Seattle, WA, April 18-19, 1977.
11. R. S. Ottinger. Industrial Waste Characterization State-of-the-Art Review. Proceeding of the 1976 ASME Conference, Halston Woods State Park, Oxford, OH, Sept. 19-24, 1979.
12. John B. Edwards. Combustion: Formation and Emission of Trace Species. Ann Arbor Science Publishers, Inc., Ann Arbor, MI, 1974.
13. Robert D. Reed. Furnace Operations. Gulf Publishing Co., Houston, TX, 1976.
14. J. J. Santoleri. Energy Recovery from Low Heating Value Industrial Waste. ASME, N75-IPWR-13, 1975.
15. J. H. Fernandes and L. J. Cohen. Burning of Waste As Fuels in Industrial Boilers. 66th Annual Meeting of the Air Pollution Control Association, June 24-28, 1978.
16. Yen-Hsiung Kiang. Liquid Waste Disposal System. Chem. Prog. 72(1), 71, (1976).
17. J. J. Santoleri. Incineration of Waste Liquids Containing Organic Compounds and Inorganic Salts. 22nd Proceedings, Institute of Env. Sci., 1976.

18. Richard D. Ross. Industrial Waste Disposal. Reinhold Book Corporation, New York, 1974.
19. Joseph Eigner. Hazardous Waste and Energy Recovery, 3rd Annual UMR-MEC Congress on Energy, University of Missouri-Rolla, 1976, p. 625-631.
20. Hidemasa Tsuruta. Waste Liquid Incineration and Valuable Recovery in the Chemical Industry. Chem. and Env. Eng. Review, 4(12), 4s, (1972).
21. Reynolds, Smith and Hill. Energy Conversion Potential of Industrial Waste Streams. Final Report on EPA Contract No. 68-01-3569, Sept. 1977.
22. Francis A. Govan and Herbert E. Beninpon. Experience With Burning Industrial Waste in Steam Generating and High Temperature Heat Recovery Systems. Proceedings of the 1976 ASME Conference, Halston Woods State Park, Oxford, OH, Sept. 19-24, 1979.
23. Richard D. Ross. Technology Options in Thermal Processing of Organic Hazardous Wastes. 79th Annual Meeting, AIChE, Houston, TX, March 18, 1975.
24. R. S. Ottinger, J. L. Blumenthal, D. F. Dal Porto, G. I. Gruber, M. J. Santy, and C. C. Shih. Recommended Methods of Reduction, Neutralization, Recovery, or Disposal of Hazardous Waste, Vol. 1, PB 224 580, Springfield, VA, NTIS, August 1973.
25. D. R. Tierney and T. W. Hughes. Source Assessment: Reclaiming of Waste Solvents, State-of-the-Art. EPA 600/2-78-004f, April 1978.
26. Marshal Sittig. Pollution Control in the Plastics and Rubber Industry. Noyes Data Corporation, Park Ridge, NJ, 1975.
27. G. J. Minhoff and C. F. H. Tipper. Chemistry of Combustion Reactions. London: Butterworths, 1962.
28. D. S. Duvall and W. A. Rubery. Laboratory Evaluation of High-Temperature Destruction of Kepone and Rotated Pesticides. EPA--600/2-76-209. U.S. EPA Municipal Environmental Research Laboratory, Cincinnati, OH, December 1976.
29. D. S. Duvall and W. A. Rubery. Laboratory Evaluation of High-Temperature Destruction of Polychlorinated Biphenyls and Related Compounds. EPA--600/2-77-228. U.S. EPA Municipal Environmental Research Laboratory, Cincinnati, OH, December 1977.
30. K-C. Lee, H. J. Jalmes, and D. C. McCauley. Thermal Oxidation Kinetics of Selected Organic Compounds. J. Air Poll. Control Assoc., 29, 749, (1979).
31. K-C. Lee, J. L. Hansen and D. C. McCauley. Predictive Model of the Time-Temperature Requirements for Thermal Destruction of Dilute Organic Vapors.

32. John L. Yates, Rajan K. Chaudhry, and James A. Dewey. An Inventory of Used and By-Product Hydrocarbon Streams. Final Report EPA Contract No. 68-03-2728, March 1980.
33. Richard D. Ross. Incineration of Solvent Air Mixtures. Chem. Eng. Prog., 68, 59, (1972).
34. L. Y. Hess. Reprocessing and Disposal of Waste Petroleum Oils, Noyes Data Corporation, Park Ridge, NJ, 1979.
35. Herbert I. Hollander. Parametric Considerations in Utilizing Refuse-Derived Fuel in Existing Boiler Furnaces. Proceed. 1976 Nat. Waste Recovery Conf., Boston, MA, May 23-26, 1976.
36. P. J. Adams, D. P. Gall, W. R. Murray, and J. W. Urrell. Overview of Wood Refuse Firing. Proceed. 1979 American Power Conference, Vol. 41, pp. 241-244.
37. A list of titles with NTIS order numbers is as follows:
 - (1) Assessment of Industrial Hazardous Waste Practices--Leather Tanning and Finishing Industry (PB-261-018)
 - (2) Assessment of Industrial Hazardous Waste Practices, Inorganic Chemicals Industry (PB-244-832/2WK)
 - (3) Assessment of Industrial Hazardous Waste Practices: Paint and Allied Products Industry, Contract Solvent Reclaiming Operations, and Factory Application of Coatings (PB-251-669)
 - (4) Assessment of Industrial Hazardous Waste Practices: Storage and Primary Batteries Industries (PB-241-204/7WP)
 - (5) A Study of Waste Generation, Treatment, and Disposal in the Metals Mining Industry (PB-261-052)
 - (6) Assessment of Industrial Hazardous Waste Practices: Organic Chemicals, Pesticides, and Explosives Industries (PB-251-307)
 - (7) Assessment of Industrial Hazardous Waste Practices, Textiles Industry (PB-258-953)
 - (8) Assessment of Hazardous Waste Practices in the Petroleum Refining Industry (PB-259-097)
 - (9) Pharmaceutical Industry: Hazardous Waste Generation, Treatment, and Disposal (PB-258-800/2WK)
 - (10) Assessment of Industrial Hazardous Waste Practices--Special Machinery Manufacturing Industries (PB-265-981)
 - (11) Assessment of Industrial Hazardous Waste Practices--Electronic Components Manufacturing Industry (PB-265-532)

- (12) Assessment of Industrial Hazardous Waste Practices, Electroplating and Metal Finishing Industries--Job Shops (PB-264-349)
- (13) Assessment of Industrial Hazardous Waste Management, Petroleum Re-Refining Industry (PB-272-267/6WK)
- (14) Assessment of Industrial Hazardous Waste Practices in the Metal Smelting and Refining Industries: Volume I (PB-276-169); Volume II (PB-276-170); Volume III (PB-276-171); Volume IV (PB-276-172)
- (15) Assessment of Industrial Hazardous Waste Practices, Rubber and Plastics Industry (PB-282-069)
- 38. N. Ostojio. End Use of Solvents Containing Volatile Organic Compounds. EPA450/3-79-032, May 1979.
- 39. P. H. Wicks and M. Synak. Oregon Surveys Its Hazardous Wastes. Environmental Science and Technology, 8, 1080, (1974).
- 40. P. F. Fennelly et al. Surveying Massachusetts' Hazardous Wastes. Environmental Science and Technology, 11, 762, (1977).
- 41. E. Iannotti, B. W. Knapp, and D. M. Quackenbush. An Inventory of Industrial Hazardous Waste Generation in New York State. Division of Solid Waste Management, New York State Department of Environmental Conservation, Albany, NY, June 1979.
- 42. J. C. Perkins et al. Hazardous or Difficult to Handle Waste Survey Report. Solid Waste and Vector Control Branch, North Carolina State Department of Human Resources, Raleigh, NC, October 1978.
- 43. Private communication. B. Radlinski, State Plan Coordinator, Division of Land/Noise Pollution Control, Illinois Environmental Protection Agency, Springfield, IL to J. W. Harrison, RTI, August 27, 1980.
- 44. Private communication. R. Freisen, Chief, Project Evaluation Branch, California Air Resources Board, Sacramento, CA, to J. W. Harrison, RTI, August 26, 1980.
- 45. Private communication. C. R. York, Chief, Division of Compliance, Air Quality Programs, Maryland Environmental Health Administration, Baltimore, MD, August 27, 1980.
- 46. T. Devitt, P. Spait, and L. Gibbs. Population and Characteristics of Industrial/Commercial Boilers in the U.S. EPA-600/7-79-178a, August 1979.
- 47. N. Y. Kirov. Waste Management, Control, Recovery, and Reuse. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1974.
- 48. C. H. Schwartz, A. A. Orning, R. B. Snedden, J. J. Demeter, and D. Bienstock. Development of a Vortex Incinerator with Continuous Feed. Presented at the 5th National Incinerator Conf., New York, June 5-7, 1972.

49. D. P. Bridge and J. D. Hummell. Incinerators Designed Specifically to Burn Waste Liquids and Sludges, ASME Conf. on Waste Incineration, 1972, pp. 55-60.
50. Joseph I. Frankel. Incineration of Process Wastes. Chem. Eng., Vol. 73(18), August 1966, pp. 91-96.
51. L. W. Coleman and L. F. Cheek. Liquid Waste Incineration. Chem. Eng. Prog., Vol. 64(9), September 1968, pp. 83-87.
52. Private communication. H. Hovey, Director, Division of Air, New York Department of Environmental Conservation, to J. W. Harrison, RTI, August 4, 1980.
53. Private communication. J. Lauber, Toxic Unit, NYDEC to J. W. Harrison, RTI, August 4, 1980.
54. Private communication. B. Cochran, S.E. Field Office (Wilmington), Division of Environmental Management, North Carolina Department of National Resources and Community Development to J. White, RTI, August 18, 1980.
55. Private communication. V. Copeland, N.E. Field Office (Washington, NC), Div. Env. Mgt., NCDNRCD to J. White, RTI, August 18, 1980.
56. Private communication. F. Johnson, N. Piedmont Field Office (Winston-Salem), Div. Env. Mgt., NCDNRCD to J. White, RTI, August 18, 1980.
57. Private communication. K. Schuster, N. Central Field Office (Raleigh), Div. Env. Mgt., NCDNRCD to J. White, RTI, August 18, 1980.
58. Private communication. W. C. Crosby, Chief, Bureau of Air Quality Control, South Carolina Department of Health and Environmental Control, Columbia, to J. W. Harrison, RTI, August 5, 1980.
59. Private communication. G. Drew, Air Protection Branch, Georgia Environmental Protection Division, Atlanta, to J. W. Harrison, RTI, August 4, 1980.
60. Private communication. J. Oberlander, S. W. Regional Office (Vancouver) Washington (State) Department of Ecology to W. J. King, RTI, August 20, 1980.
61. Private communication. R. West, Chemical Processors, Inc. to W. J. King, RTI, September 4, 1980.
62. Private communication. R. Reiter, Solid Waste Division, Oregon Dept. of Environmental Quality, Portland, to J. W. Harrison, RTI, August 5, 1980.
63. Private communication. J. Taylor, Pollution Control Department, Harris County, Texas, to W. J. King, RTI, August 21, 1980.

64. Private communication. J. Caraway, Combustion Permit Section, Texas Air Control Board, Austin, to W. J. King, August 26, 1980.
65. Private communication. D. Walsh, Hazardous Waste Division, Massachusetts Department of Environmental Quality Engineering, Boston, to J. W. Harrison, RTI, August 22, 1980.
66. Private communication. K. Hagg, Director, Division of Air Quality, Mass. DEQE, to J. W. Harrison, RTI, August 25, 1980.
67. ASME Research Committee on Industrial and Municipal Waste. Combustion Fundamentals for Waste Incineration. ASME, New York, 1974.
68. _____. Thermodynamic Data for Waste Incineration. ASME, New York, 1979.
69. _____. Disposal of Industrial Wastes by Combustion. ASME, New York, 1977.
70. R. A. Matula, editor. Proceedings of the 1976 ASME Conference on the Present Status and Research Needs in Energy Recovery from Waste, Halston Woods State Park, Oxford, OH, September 19-24, 1976. ASME, New York, 1976.
71. J. H. Fernandes. Design and Operating Factors for Burning Waste Materials in Industrial Boilers. Plant Engineering, June 26, 1975, pp. 83-85.
72. CC. Ferguson. Tar Burning on Boilers at Algoma. Iron and Steel Engineer, July 1980, pp. 29-32.
73. E. M. Mockridge. Utilization of Package Boilers for the Combustion of Waste Fuels, pp. 649-656 in Proceedings of the American Power Conference, Volume 36, Illinois Institute of Technology, Chicago, 1974.
74. J. H. Fernandes and R. C. Shenk. Solid-Waste Fuel Burning in Industry. pp. 663-670 in Proceedings of the American Power Conference, Volume 36, Illinois Institute of Technology, Chicago, 1974.
75. W. J. Matthys. Retrofitting Industrial Boilers to Meet the Fuels Market, pp. 735-741 in Proc. American Power Conference, Volume 37, Illinois Institute of Technology, Chicago, 1975.
76. C. A. Hescheles. Industrial Waste Analysis and Boiler Performance Test Burning Wastes, ASME Paper 66-WA/PID-11, July 1966.
77. M. E. LePera and G. DeBono. Investigating Waste Oil Disposed by Direct Incineration. Report 2127, U.S. Army Mobility Equipment Research and Development Center, Ft. Belvoir, VA, February 1975.
78. S. Chansky et al. Waste Automotive Lubricating Oil Reuse as a Fuel. EPA-600/5-74-0032. U.S. EPA Office of Research and Development, Washington, DC, September 1974.

79. H. Ikebe et al. Some Examples of Combustion Tests for Putting New Fuels to Practical Use. IHI Engineering Review 9(4), 1, (1976).
80. W. Hart. Combustion and Heat Recovery from Polymeric Materials. pp. 371-379 in proc. Conf. on Present Status and Research Needs in Energy Recovery from Waste, Houston, 1976. New York: American Society of Mechanical Engineers, 1976.
81. L. E. Reed and S. C. Wallin. The Effect of Operating Conditions on the Performances of Different Types of Oil Burners. J. Inst. Fuels 34, 26, (1961).
82. J. H. Wasser, R. P. Hangebrauck, and A. J. Schwartz. Effects of Air-Fuel Stoichiometry on Air Pollutant Emissions from an Oil-Fired Test Furnace. J. Air Poll. Control Assoc. 18, 332, (1968).
83. K. Skoog and F. Petersen. Particle Emission from Oil-Fired Heating Plants. pp. 412-417 in F. J. Weinberg (ed), Combustion Institute European Symposium, 1973, London: Academic Press, 1973.
84. D. H. Cotton, N. J. Friswell, and D. R. Jenkins. The Suppression of Soot Emission from Flames by Metal Additives. Combustion and Flame 17, 87, (1971).
85. A. Fengier. The Effect of Alkali Metals on the Amount of Soot Emitted by Promised Carbon Flames. pp. 406-411 in Weinberg (see Ref. 83).
86. G. B. Martin, D. W. Pershing, and E. E. Borkan. Effects of Fuel Additives on Air Pollutant Emissions from Distillate-Oil-Fired Furnaces. AP-87, Office of Air Programs, U.S. EPA, Research Triangle Park, NC, June 1971.
87. L. P. Sullivan, Jr. Control Systems for Waste Fuel Burners in Industrial Steam Generators. ASME Paper 77-IPC-Pwr-6, presented at ASME Industrial Power Conference, Cleveland, October 23-26, 1977.
88. R. P. Hangebrauck, D. J. Von Lehmden, and J. E. Mecker. Emissions of Polynuclear Hydrocarbons and Other Pollutants from Heat-Generation and Incineration Processes. JAPCA 14, 267, (1964).
89. B. T. Commins. Formation of Polycyclic Aromatic Hydrocarbons During Pyrolysis and Combustion of Hydrocarbons. Atmos. Environ. 3, 565, (1969).
90. B. B. Chakraborty and R. Long. The Formation of Soot and Polycyclic Aromatic Hydrocarbons in Diffusion Flames--Part I. Combustion and Flame 12, 226, (1968).
91. Task Force on Hazardous Waste, American Society of Mechanical Engineers. Comparison of Full-Scale Incinerator Performance with the EPA Proposed Hazardous Waste Guidelines. January 21, 1980, Submitted to OSW.

92. North American Combustion Handbook. Second edition. North American Manufacturing Co., Cleveland, OH, 1978.
93. R. R. Reiche (ed.). Combustion Technology Manual. Second Edition. Industrial Heating Equipment Association, Washington, DC, 1974.
94. R. H. Essenhigh. An Introduction to Stirred Reactor Theory Applied to the Design of Combustion Chambers. p. 389 in H. B. Palmer and J. M. Beer (eds.), Combustion Technology, Academic Press, New York, 1974.
95. M. A. Dalin. Control Requirements for Industrial Boilers. pp. 805-827 in Proc. Am. Power Conf., Volume 35, Illinois Institute of Technology, Chicago, 1973.
96. R. E. Pocock. New Instruments and Controls Save Purchased Fuels and Burn Waste Fuels Efficiently. ASME Paper 77-IPC-Pwr-5, August 1977.
97. L. P. Sullivan, Jr. Control Systems for Waste Fuel Burners in Industrial Steam Generators. ASME Paper 77-IPC-Pwr-6, August 1977.
98. Reference 2, p. 33216.
99. Reference 2, p. 33250.
100. Reference 2, p. 33092.
101. Reference 2, p. 33173.
102. Reference 2, p. 33123.
103. Reference 2, pp. 33142-33148.
104. Reference 2, p. 33120.
105. Private communication. A. Sheehan, Hazardous Waste Division, USEPA-OSW, Washington, DC, to J. W. Harrison, RTI, September 9, 1980.
106. 40CFR52, Subparts F (California) and W (Massachusetts).
107. New York State Dept. of Env. Conservation Regulation 212 (Amended) Process and Exhaust and/or Ventilation Systems. March 24, 1979.
108. Private communication. H. Hoven, Director, Division of Air, NYSDEC, to J. W. Harrison, RTI, August 4, 1980.
109. Private communication. K. Hagg, Director, Div. Air Quality Control, Massachusetts DEQE, Boston, to J. W. Harrison, September 12, 1980.
110. Mass. DEQE Regulations. 310 CMR 7.00: Air Pollution Control Regulations, July 1, 1979.
111. *ibid.*, Section "Definitions".

112. Private communication. C. York, Chief, Div. of Compliance, Maryland Env. Health Admin., Baltimore, to J. W. Harrison, RTI, August 27, 1980.
113. Private communication. J. Caraway, Combustion Permit Section, TACB, Austin, to W. J. King, RTI, August 26, 1980.
114. Clean Air Act, as amended, Section III.
115. Private communication. C. Sedman, ESED, USEPA-OAQPS, Durham to J. W. Harrison, RTI, September 15, 1980.